From plantation towards close-to-nature forestry

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Operational Studies of Shelterwood Regeneration and Selection Management in Norway Spruce

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ABSTRACT

Close-to-nature forestry may contribute to fulfil the objective of sustainable forestry. In some cases close-to-nature forestry can be implemented by adjusting the silvicultural system while more radical changes are necessary in other cases. Conversion of even-aged monocultures of Norway spruce to more stable stands has high priority, and should be done before close-to-nature forest management systems such as selection management can be implemented.

Conversion of an even-aged spruce stand on the former heath-land in north-western Denmark was studied from an operational point of view. Time consumption was studied on the establishment of the shelterwood, on different methods of site preparation and on the planting operation. Damages to the shelter trees were studied, and wind-thrown trees were registered. Mortality of the planted seedlings was analysed and natural regeneration was registered. Harvesting productivity of selection management systems was studied in an uneven-aged stand in south-eastern Norway.

The short-wood system gave higher net income than the chip harvesting system in the shelterwood establishment, but changes in price relations or lower stand quality might reverse this. The damage rate seems to be negatively correlated with productivity. In site preparation, the tractor-drawn implements showed higher productivity than boom-mounted equipment, but the thorough preparation made by the boom-mounted implements ensured better survival of the seedlings. Highest mortality was found for planting without site preparation. Planting productivity was higher in site prepared soil than in unprepared soil, and the increased planting productivity could justify site preparation with tractor-drawn implements itself. Loosely suspended tractor-drawn implements cause considerable damage, and the intensive digging made by the excavator destabilises the shelterwood. Natural regeneration was favoured by site preparation, but the natural regeneration almost exclusively consisted of Norway spruce. Therefore planting or sowing is necessary in order to introduce other species in the heath plantations.

The productivity of a single-grip harvester in single-tree and group selection management systems showed only minor differences. The difference in tree-size and the difference thinning intensity determined the productivity. In group selection the tree size was small and the degree of thinning high, while the tree size was bigger and the degree of thinning lower in single tree selection. The two factors compensated each other.

Keywords: chip harvesting, damages, injuries, mortality, natural regeneration, Norway spruce, planting, productivity, selection management, shelterwood regeneration, short-wood harvesting, site preparation, time study, work quality.

CONTENTS

APPENDIX

PAPERS I-V

The present thesis is based on the following papers, which will be referred to by their roman numbers.

I Suadicani, K. & Nordfjell, T. 2002. Operational aspects of two thinning methods in the establishment of a shelterwood in a medium-aged Norway spruce stand. Manuscript.

II Suadicani, K. 2002. Fuel chips production in a medium-aged Norway spruce stand. Manuscript.

III Suadicani, K. 2002. Site preparation and planting in a shelterwood of Norway spruce – Technical feasibility and seedling mortality. Manuscript.

IV Suadicani, K., Hansen, L. P. & Heding, N. 2002. Natural regeneration in a shelterwood of Norway spruce on former heathland. Article accepted for publishing in Baltic Forestry.

V Suadicani, K. & Fjeld, D. 2001. Single-tree and group selection in montane Norway spruce stands: Factors influencing operational efficiency. Scand. J. For. Res. 16: 79-87.

INTRODUCTION

A sustainable forestry being ecologically stable and having high biodiversity is accepted as a strategic objective in most countries. This was stated by the Brundtland-Commission, at the UN-Conference in Rio de Janeiro, and at the ministerial conferences on the protection of forests in Europe in Strasbourg, Helsinki, and Lisbon (Anon 1993, Anon. 2000). Close-to nature forestry has come into focus as an interesting forest management system because it seeks to use the natural processes to establish and maintain a diversified stand structure based on native species (or species believed to function as a part of the ecosystem) that are able to regenerate naturally (e.g. Larsen 1995, Otto 1995 a, b). Implementation of close-to-nature forestry often includes changes in the species composition as well as changes in the stand structure. If the stand already consists of site-adapted species that are able to regenerate naturally, the primary target is to introduce a management system that increases diversity in the stand structure. If the stand has an unsuitable tree species composition, it is necessary to introduce other tree species that are able to form stable stands and regenerate naturally (Kazda & Pichler 1998, Mosandl & Küssner 1999, Madsen & Löf 2000). When other species are introduced into the stand, the next step is to implement a management system that increases the diversity in the stand structure and leads towards close-to-nature forestry[1] (Küssner 1997, Kenk & Guehne 2001, O'Hara 2001, Schütz 2001).

The boreal forests mostly consists of well-adapted, native species (e.g. Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus silvestris* L.) and Birch (*Betula sp.*), and therefore the introduction of a management system improving the structural diversity, such as selection management, is the primary target towards close-to nature forestry. In the sub-alpine and pre-taiga area of the boreal forests the climatic conditions are extreme even for the well-adapted species. Natural regeneration is sparse because seeding is infrequent and because conditions for germination are difficult. The management must focus on facilitating regeneration by establishing the best possible microclimatic conditions (Solbra 1989). Selection management systems such as single-tree selection or group selection have been used for a long time, based on manual or motor-manual harvesting systems, but modern harvesting systems based on single-grip harvesters and forwarders need to be introduced.

In the temperate forests of Europe Norway spruce has been planted far beyond its natural range, because is has been considered economically

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1 In this thesis, keywords for close-to-nature forestry include permanent tree cover, site-adapted tree species, natural regeneration and varied stand structure.

superior to other species (Schmidt-Vogt 1987). Unfortunately many of these stands have shown symptoms of ecological instability, and many efforts are made in order to convert such Norway spruce stands to other types of stands. (e.g. Otto 1995a, b, Hehn 1997, Hasenauer & Sterba 2000, Matthes & Ammer 2000). Although not indigenous, Norway spruce dominates the heath-land plantations in western Denmark. Here, it also shows symptoms of ecological instability. It is susceptible to windthrows, to root and butt rot (mostly *Heterobasidion annosum* (Fr.) Bref. and *Armillaria mellea* (Vahl ex Fr.) Kumm.), to drought, warm winters, and to air pollution. (Hviid 1957, Clausen 1995). A conversion of parts of the heath plantations is therefore highly prioritised in Denmark. Shelterwood regeneration is the most promising system (Jakobsen & Emborg 2000), but little knowledge of operational aspects exists.

In the windy climate of western Denmark shelterwoods in fully-grown stands are often subject to windthrows. Less tall stands are more wind-resistant, and therefore shelterwood regeneration in medium-aged stands (height <15 meters) has been proposed (Løfting 1949, Oksbjerg 1951, Henriksen 1971). Neckelmann (1995) demonstrated that the stability was good in such stands, and the diameter increment on the shelter trees was high, provided the stand was vigorous. Because of the smaller size of the individual trees, shelterwoods in medium-aged stands must consist of more trees as compared to shelterwoods in fully-grown stands.

Establishment of shelterwoods in medium-aged stands can be achieved by short-wood harvesting of industrial round wood, as whole-tree chipping of fuel-chips or as integrated harvesting (combined production of industrial round wood and fuel-chips). In stands without too much root rot, short-wood harvesting is expected to give the best economic result, while whole-tree chipping is an option in stands of poor quality. Integrated harvesting might be superior if high quality saw-logs can be produced in the butt end, while the top end is not suitable for production of round wood assortments. The short-wood harvesting system is quite well known. The system has been analysed in detail with most efforts laid in studies of single-grip harvester productivity (Brunberg et al. 1989, Fjeld 1992, Fjeld 1994, Westerberg et al. 1996, Lageson 1997, Eliasson et al. 1999, Hånell et al. 2000). In the establishment of a shelterwood, additional constraints apply to tree selection compared to ordinary thinning, especially if site preparation follows. The same constraints apply to whole-tree chipping system and integrated harvesting, but a more urgent challenge in Denmark is to adapt the widely used terrain-chipping system to a larger tree size than it was originally designed for. A consequence of introducing chipping systems in stands with larger tree-size is that integrated harvesting might become an alternative to whole-tree chipping.

The introduction of new tree species is the objective of a conversion process, and most often planting (or sowing) is necessary because relevant seed sources are missing. Site preparation is most often considered necessary on clear-cut areas characterised by a thick humus layer such as in the heath plantations in western Denmark. Site preparation removes the humus layer and permits planting (or sowing) directly in the mineral soil. Site preparation is also relevant in a shelterwood, but the shelter-trees obstruct the access to the stand, which complicate the site preparation process. The roots of the shelter trees will unavoidably be damaged by site preparation, which reduces the physical stability of the shelterwood. Stem damages on the shelter trees might also occur (Fjeld 1996, Hagner 1990, Westerberg & Hofsten 1996). Because of the high number of trees in shelterwoods in medium-aged stands, site preparation must be carefully considered. Different site preparation implements are available, and increased knowledge of their positive and negative effects on the shelterwood and the regeneration is needed.

Although the introduction of additional species is a main target for the conversion process, a proportion of the seedlings could come from natural regeneration. It would reduce the regeneration costs considerably if the number of planted seedlings could be reduced and replaced by natural regeneration. Site preparation facilitates natural regeneration as it facilitates planting and sowing, and therefore site preparation can be done in order to facilitate all types of regeneration.

Objectives

Conversion by shelterwood regeneration in medium-aged Norway spruce stands is the first step in a long-sighted change of the management system. Decades will pass before a close-to-nature management system will be fully implemented in these stands. This thesis covers the whole process starting with a conversion and ending with an example of a close-to-nature management system. In a series of five, four articles focus on different aspects in the conversion of a medium-aged Norway spruce stand by shelterwood regeneration. The result of this conversion can not be seen yet, although the regeneration seems promising. In twenty years or so the shelterwood should be fully removed, and it is time to decide how to manage the new stand. A selection management system could very well be chosen because it favours the principles of close-to-nature forestry. The last article analyses the operational efficiency of different selection management systems in a forest already managed according to the principles of close-to-nature forestry. Although this study was done at a very different location, it might give some inspiration to how selection management practise can be implemented in converted stands in the heath plantations.

The aim of the studies in article I and II was to determine productivity, costs, and damage rate in the establishment of a shelterwood in a medium-aged Norway spruce stand. Conventional short-wood harvesting, whole-tree chipping and integrated harvesting was analysed.

The aim of the studies in article III and IV was to determine the effect of different site-preparation methods on planting and natural regeneration. Six different site preparation methods were studied, and four different species were planted. The influence of site preparation on the mortality of the planted seedlings and on the density of the natural regeneration of Norway spruce was analysed.

The aim of the study described in article V was to compare the productivity of a single-grip harvester in single-tree and group selection management systems in montane Norway spruce. Three harvest intensities of single-tree selection and two group sizes of group selection were studied.

MATERIALS AND METHODS

The conversion studies (I-IV) took place in north-western Denmark. Terrain conditions for the site were very good, but the soil was poor and sandy and covered by a layer of raw humus. Ninety five percent of the trees were Norway spruce, but some silver fir (*Abies alba* Mill.), grand fir (*Abies grandis* Lindl.), Scots pine and larch (*Larix decidua* Mill.) were also found. A striproad system divided the stand into 108 plots (57×15m) each consisting of approximately 9 tree rows. Short-wood harvesting (two thinning methods termed row and selective thinning) was performed in one part of the stand. In the other part, three whole-tree-chipping systems and one integrated-harvesting system was studied. The harvesting studies resulted in one part of the stand where site preparation implements had easy access to the stand (row thinning), and one part of the stand where the distribution and quality of the shelter trees was given priority (selective thinning)(Fig. 1). Each of the four parts in Fig. 1 was divided into six smaller units for site preparation. Each of those 24 site preparation units was further divided into plots for planting.

The selection management study (V) took place in an uneven-aged stand of Norway spruce in south-eastern Norway at an elevation of 600 m. Terrain conditions were acceptable for ground-based machines. Two blocks were selected and 8-9 plots were laid out in each block. The treatments included three harvest intensities of single-tree selection (25, 45 and 65% reduction of basal area) and two group sizes of group selection (25×25 and 50×50 m). Establishment of striproads was also studied. A Valmet 901/948 Harvester did the harvesting, and all trees to be felled were marked.

In the conversion study, a Silvatec 656 TH harvester and a Valmet 820 forwarder did the short-wood harvesting operating from striproads (distance 15 m) parallel to the tree rows. In selective thinning, the instruction was to leave 50-60% of the most vigorous trees uniformly spaced. In row thinning, the instruction was to remove every second tree row in order to obtain easy passage for site preparation implements. A tree row was not to be removed, if this would cause larger gaps in the stand structure. If so, the adjacent tree row should be removed (shifting row for a distance), still having in mind easy passage for site preparation implement.

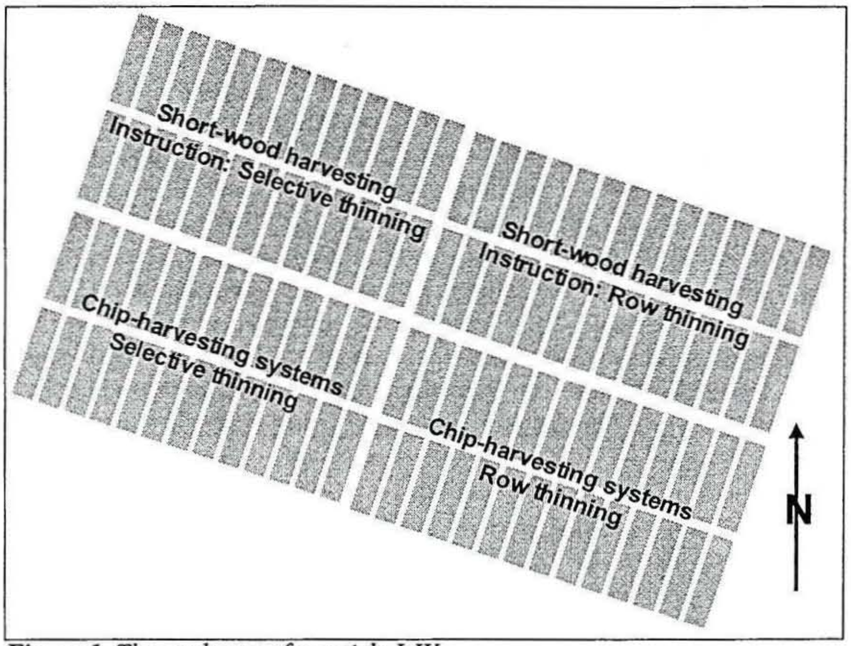

Figure 1. *The study area for article I-IV.*

The whole-tree chipping systems had different felling operations (1) Motor-manual felling, (2) felling and bunching at the striproads with a Silvatec 854 TH feller-buncher and (3) felling in herringbone pattern with a Silvatec 656 TH harvester. The integrated harvesting (4) was also performed by felling in herringbone pattern with the Silvatec 656 TH harvester, but the felling included production of a piece of saw log in the butt end when possible. All chipping was performed in the stand with a Fendt Favorit 614 LSA/TP-960 chip-harvester, and a Fendt 308/Spragelse did the terrain transportation. As with the short-wood system no trees were marked prior to felling.

Site preparation was carried out manually with a forest spade, and mechanically with three tractor-drawn (Loft disc plough, Kulla mill harrow, and Polyteknik drum rotator) and two boom-mounted implements (Hanix n450 excavator and a prototype soil auger). Planting (of bare-rooted seedlings) was done manually.

The stands were measured both before and after harvesting. Productive work time for harvesting, extraction, site preparation and planting were recorded in continuous time studies using SIWORK3 software and a Husky Hunter computer. All analyses were done in SAS version 6.12 (Anon. 1989a, b). Work place time was calculated according to Samset (1995). In the conversion study, damages to the shelter trees were recorded both after harvesting and after site preparation. Site preparation intensity was measured after site preparation as well as the mortality of the planted seedlings and the number of naturally regenerated seedlings two years after planting. The number of windfalls three years after establishing the shelterwood was also measured.

The productive work time was divided into sub-operations that were analysed separately. In the harvesting studies, the productive work time was divided into positioning, processing, moving and preparation time (in the selection management study, positioning was a part of processing time). In the study of forwarding, the productive work time was divided into loading, driving while loading, adjusting the load, driving with full load, driving with empty load and unloading. In the felling and chipping study, the productive work time was divided into felling/chipping, moving and miscellaneous. In the site preparation study the productive work time was divided into scarification, positioning and turning time. In the planting study, the productive work time was divided into planting and preparation time.

RESULTS

The harvesting studies (I, V) confirmed the strong effect of tree-size on processing time. In the conversion study (I) both processing and positioning took longer if trees were harvested far away from the striproad, and they took longer in row thinning compared to selective thinning (Fig. 4 in I). In the selection management study (V), differences in processing time between the treatments could not be found, except for differences explained by different tree-sizes.

It was found that moving time per ha increased with increasing harvest intensity (I) and that number of trees per position increased by increased harvest intensity if single-tree and group selection were analysed together (V). If the results from single-tree selection (V) were merged with study I, a clear correlation between the number of positions and the harvesting intensity could be found, showing a somehow constant number of harvested trees per position in thinning (Fig. 2). The moving time per position decreased with increasing harvest intensity. The harvesting productivity (based on work place time) was approximately 12 m^3 h^{-1} in study I and approximately 14 m^3 h^{-1} in study V. The difference could be explained by the difference in tree-size.

Highest chipping productivity was found in the feller-bunched areas, while the productivity was low where the harvester did the felling (II). Trees with diameter more than 28 cm in the root end could not be fed into the chipper directly. Around 1% of the trees was so big that a stump had to be cut off before whole-tree-chipping. No treetops were too large for chipping in integrated harvesting. Felling productivity was approximately the same for the feller-buncher and the harvester, while integrated harvesting took longer time. Motor-manual felling had the lowest productivity, but anyhow it was the most cost-effective felling method.

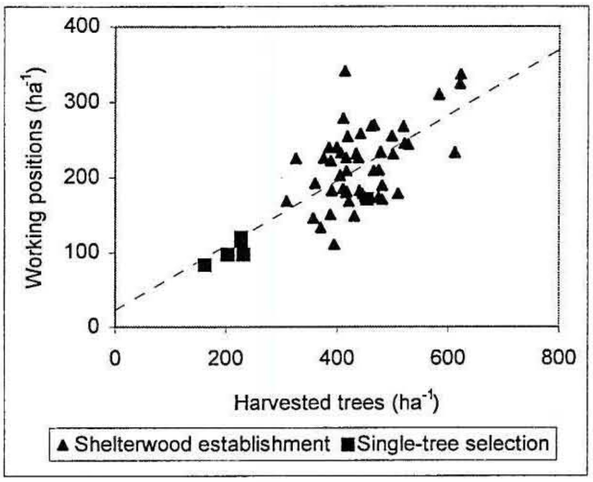

Figure 2. Number of working positions as a function of harvested trees. R^2=0.49.

The total work place time to roadside was lower for the short-wood systems (I) than for the chip-systems and integrated harvesting (II). Whole-tree chipping was more productive after felling with feller-buncher than after felling in herringbone pattern with a harvester. Integrated harvesting had approximately the same the total work place time consumption as whole-tree chipping after felling in herringbone pattern with a harvester (Fig. 3).

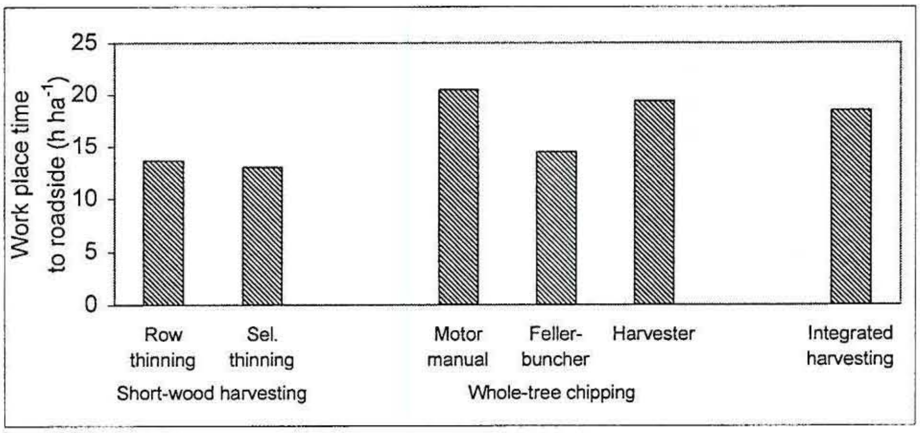

Figure 3. Time consumption for the shelterwood-harvesting systems studied in article I and II.

The income was higher for the short-wood harvesting and integrated harvesting than for whole-tree chipping, while the costs were higher for integrated harvesting and whole-tree chipping after felling in herringbone pattern with a harvester than for whole-tree chipping of trees in lines and short-wood harvesting. Short-wood harvesting therefore gave the highest net-income (Tab. 1).

Table 1. *Income and costs at roadside (Euro ha^{-1}).*

	Short-wood harvesting		Whole-tree chipping			Integrated harvesting
	Row thinning	Selective thinning	Motor-manual felling	Feller-buncher felling	Harvester felling	
Income at roadside	1828	1828	1512	1512	1512	1796
Costs at roadside	1337	1259	1255	1247	1708	1664
Net income	491	568	257	265	-196	132

In the analyses of injuries to the shelter trees, it was found that the most efficient systems caused the least damage to the shelterwood. Difficulties in the work (as seen in row thinning in study I and in chipping of trees in herringbone pattern in study II) resulted in more injuries on the shelter trees (Fig. 4).

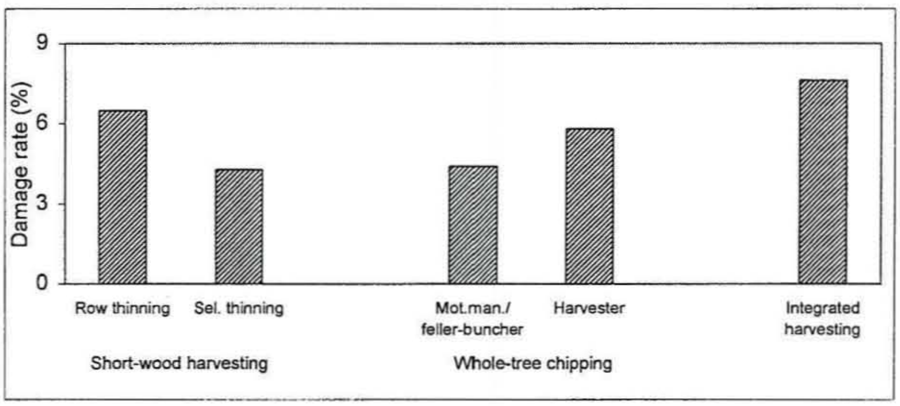

Figure 4. *Rates for damages on shelter trees.*

The site-preparation study (III) showed large difference in time consumption between the different site preparation implements (Fig. 5). The fastest implement took less than 25% of the time for the slowest. Planting took much longer in unprepared soil than in mechanically site prepared soil, but no difference in time consumption for planting could be found between the five mechanical site preparation methods. The economic analysis showed that the lower planting costs more than compensated for the site preparation costs for the most cost-efficient implements. On the contrary, site preparation costs was so high for the boom-mounted implements that higher regeneration costs must be expected compared with planting in unprepared soil (Tab. 5 in article III).

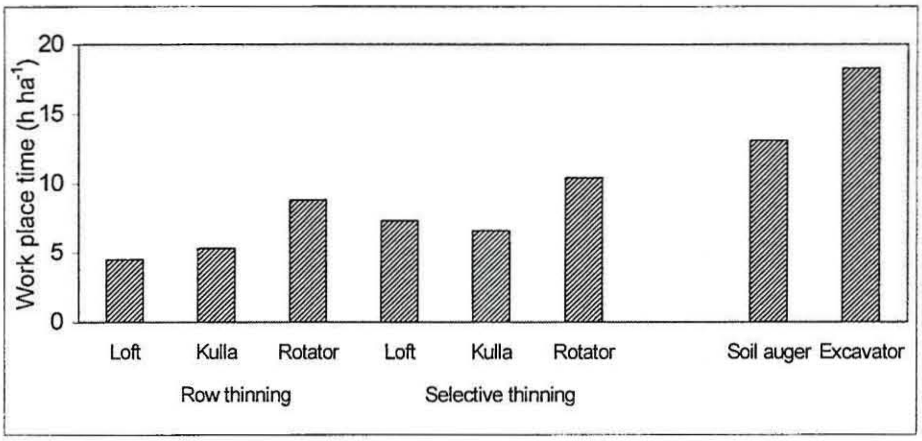

Figure 5. *Time consumption for site preparation.*

An acceptable number of seedlings was planted in all treatments except where the excavator did the site preparation (III). Significant mortality (defined as more than 5%) two years after planting was only found for beech (*Fagus sylvatica* L.) and Douglas fir (*Pseudotsuga menziesii* (Mirb. Franco), while the mortality was low for silver fir and oak (*Quercus robur* L.). Mortality varied inversely with site preparation intensity for all four tree species: High mortality without mechanical site preparation, medium mortality where tractor drawn implements did a superficial site preparation, and low mortality in thorough site prepared soil after the boom-mounted implements (Fig. 6).

Site preparation resulted in injuries on the shelter trees. The soil auger damaged only 1-2% of the shelter trees because the base machine was restricted to the striproads. The Kulla mill-harrow damaged 7-13% of the shelter trees, because the implement was loosely suspended on the tractor. The other implements damaged 3-5% of the shelter trees.

Only 45 of the 4758 trees were wind thrown three years after the shelterwood was established. 40% of these (18 trees) toppled in plots prepared with the excavator while 7-16% (3-7 trees) toppled in plots prepared by each of the other site-preparation methods.

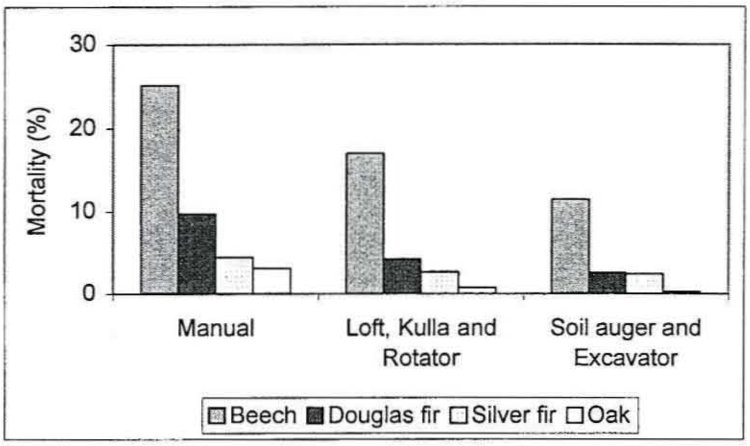

Figure 6. *Mortality for planted seedlings.*

Mechanical site preparation resulted in 3-6 times more natural regenerated Norway spruce seedlings than manually site preparation (IV). Natural regeneration was most frequent where sample plots were placed on site prepared soil. In the mechanised site prepared plots, natural regeneration was also more frequent where site preparation was not visible, because driving had caused some compaction and soil disturbance (Tab. 2 in article IV).

DISCUSSION

Differences in processing and positioning time were found between the two thinning methods in the conversion study (I). The same was expected between single-tree and group selection in the study of selection management (V) because residual trees were expected to obstruct the harvesting more in single-tree selection, and because a longer average distance from the harvester to the tree was expected here. However, the low stocking of the stands and the short distance between the striproads may have enabled the operator to handle the trees rather unimpaired by the residual stand.

The studies of moving time (I and V) showed that the number of harvested trees per position is around two in thinnings (single-tree selection and shelterwood establishment as shown in Fig. 2), while more trees are harvested per position in clear-cuts (and group selections). Although the moving time per position decreased by increasing harvest intensity, the total moving time per ha increased. The conclusion is that a substantial part of the moving time seems to be used for positioning the harvester head towards the trees the same way as positioning time. This was supported by the fact that the average positioning time was shorter after the machine had moved than after processing a tree.

In study I, a larger average tree-size was expected in row thinning as compared to selective thinning, but no difference was identified (the reasons for this are further discussed in article I). In study V significantly larger sized trees were harvested in single-tree selection than in group selection. Larger tree-size improves the net income markedly. Not only because the harvesting productivity increases, but also because the assortments from larger trees are more lucrative than those from smaller trees (Suadicani 1999). In general, a management system should therefore maximise the amount of large trees and minimise the amount of small trees. From this point of view, single-tree selection should be preferred to group selection, and probably also uneven-aged management to even-aged management.

The terrain-chipping system (II) could be adapted to larger tree-size, but the size of the chipper's feed opening sets a limit to the system. In integrated harvesting only the tops are chipped and therefore tree-size does not set the same limit.

The absence of root rot was the principal reason why short-wood harvesting turned out to be more economical than whole-tree chipping. If root rot had been present, time consumption would have increased, and yield would have decreased resulting in a lower net income in short-wood harvesting. If only pulpwood were produced (the saw-logs prices were reduced to pulpwood prices), the income would decrease with more than 500 Euro reducing the net income to round zero, and whole-tree chipping would be more economical than short-wood harvesting. Integrated harvesting would also be negatively affected by root rot, while it would have little influence on whole-tree chipping.

The integrated harvesting system would have been more competitive if the pulpwood prices were lower and the saw-log prices higher. An alternative way of performing the integrated harvesting system could be to harvest both saw logs and energy wood as round wood with the harvester the same way as harvesting saw logs and pulp wood in the short-wood system. The additional time consumption for producing the energy round wood would have been 20-25%, which can be seen by comparing harvesting time consumption in integrated harvesting (II) and in short-wood harvesting (I). Suadicani & Pedersen (1995) and Suadicani (1996) have evaluated such systems, and the analysis showed that the short-wood system for fuel wood production could be competitive, if chipping facilities were available at the heating plants. Chipping of tops and branches after conventional harvesting (of saw logs and pulpwood) could be considered, but would probably not be economical, because too little biomass is left. If the energy fraction is sparse, it might be more economical to let the chip harvester work without a chip forwarder, but this is only relevant if the terrain-transportation distance is short (Kofman 1993).

The smaller work-tasks, the more time is used for moving between them. The number of machines put into action is therefore especially important if each work-task is small, which is often the case in Denmark. Especially integrated harvesting (II) needs many machines operating on the same area (Fig. 7). Instead of using a harvester and a forwarder, integrated harvesting can be done with a combined harvester/forwarder. This type of machine is designed to handle trees in upright position and to place the butt logs directly on the load. Terrain transport is done immediately and the tops can be placed properly for chipping. The productivity of a combined harvester/forwarder, used this way, will only be slightly affected by the amount of saw logs, because loading is a part of the harvesting operation and because terrain-transportation is done when the load is full or when the harvester/forwarder is close to the stack. Contrary, the productivity of a forwarder is much dependent on the density of the assortments. A combined harvester/forwarder can also be used in short-wood harvesting (I) which is also especially relevant if the work-tasks are small and dispersed.

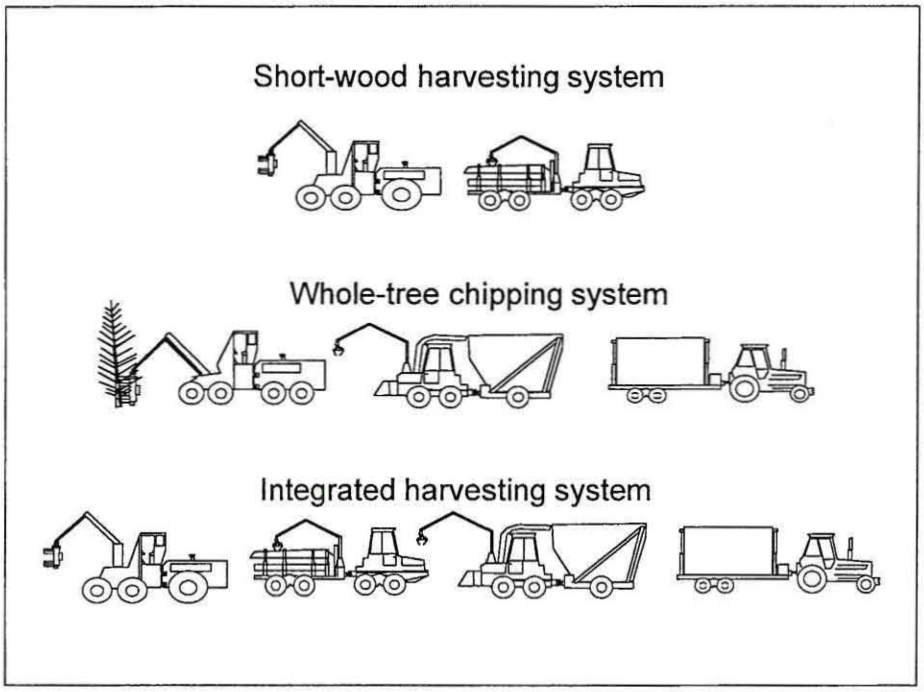

***Figure** 7. Harvesting systems.*

The feller-buncher was too small to handle large trees in an upright position especially if the boom was overly extended. If the feller-buncher were to be used on the whole area it would have been necessary to add an extra striproad between the original striproads to reach all the trees. Alternatively a larger feller-buncher should have been used. Felling in herringbone pattern did not work well because the trees were not placed properly for chipping, but a chipper able to feed trees lying more angled to the striproad might have changed the conclusion. Chipping costs comprised at least 70% of the harvesting costs at roadside, and therefore easy feeding of the chipper must be given priority.

There seems to be a lower damage rate where the harvesting systems worked well (I and II). Siren (2001) came to the same conclusion when he studied damages from harvesting with single-grip harvester.

The high mortality of seedlings planted in unprepared soil compared with seedlings planted in mechanically site prepared soil seems to be a result of a poorer planting (III). Water supply might have played a role, but it seem to have had little influence on mortality because no weed was present and because the precipitation was high during the first years after planting.

Site preparation with tractor-drawn implements is cheap if accessibility is good, and in most cases an acceptable planting follows the site preparation. Boom-mounted implements might be relevant if the accessibility is bad, and sensitive species seems to have a lower mortality in thoroughly site prepared soil, because of a better planting. The productivity of the boom-mounted implements is low and the costs are high, and such site preparation should be carefully considered.

Although the material only consisted of 45 windfalls it seem reasonable to conclude that the excavator destabilised the stand. A superficial site preparation with an excavator (Westerberg & Hofsten 1996) should have been preferred.

It seems quite relevant to use the natural regeneration of Norway spruce as supplement to planted seedlings (IV), but the planted seedlings are much larger than the naturally regenerated seedlings. One solution is to postpone the planting until natural regeneration has been established, but then most site preparation methods must be excluded because they will cause too much damage to the natural regenerated seedlings. If the soil auger is used, the site preparation and planting can be done after the establishment of the natural regeneration. Other species could also be introduced by sowing, and sowing is much easier to combine with natural seed fall. Study IV indicated that sowing of species such as beech and oak is possible, and investigations of this should be initiated.

Regeneration of different species (planted or naturally regenerated) under the same shelterwood means that the density of the shelterwood must be suitable for all species. Silver fir and beech prefer dense and prolonged shelter while oak and Norway spruce prefer a less dense and short-lived cover. This problem has not been investigated sufficiently yet.

The boreal forests in Scandinavia have a large variation in tree-size, and the short-wood harvesting system, originally designed for these forests, is therefore partly adapted to harvesting in uneven-aged stands. The short-wood harvesting system worked well in the selection management systems studied in south-eastern Norway, and the systems might be implemented in mixed stand such as the one established in the shelterwood, but the mixture of different species complicates the harvesting.

CONCLUSION

Shelterwood regeneration in medium-aged Norway spruce stands is a suitable method for conversion of stands in the heath-land areas in western Denmark. Selection management systems can be carried out with single-grip harvesters.

- Single-grip harvesters are flexible machines able to perform a wide variety of different types of harvests. Anyhow an unsuitable thinning method or thinning instruction might have a negative influence on both productivity and work quality.
- Terrain chipping systems must be designed in a way that facilitate the chipping operation. Trees felled in herringbone pattern are not easily chipped.
- Integrated harvesting systems might be more relevant when combined harvester/forwarders are available.
- Site preparation reduces mortality of planted seedlings probably because of a better planting. Site preparation also increases natural regeneration. A superficial site preparation seems to be sufficient if natural regeneration should be favoured.

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Due to restrictions from the publisher of the journal in which paper V has been published, this paper is not present in this PDF. The paper can be found in:

Paper V:
Suadicani, K. & Fjeld, D. (2001). Single-tree and Group Selection in Montane Norway Spruce Stands: Factors Influencing Operational Efficiency. *Scandinavian Journal of Forest Research, 16*, 79-87.

The rest of the papers published as part of this PhD-thesis, papers I-IV, are now all published. They are still available in this PDF, as pre-print editions. The published papers can now be found here:

Paper I:
Suadicani, K. & Nordfjell, T. (2003). Operational Aspects of Row and Selective Thinning in the Establishing of a Shelterwood in a 50-Year-Old Norway Spruce Stand. *International Journal of Forest Engineering, 14*, 25-37.

Paper II:
Suadicani, K. (2003). Production of fuel chips in a 50-year old Norway spruce stand. *Biomass and Bioenergy, 25*, 35-43.
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Paper III:
Suadicani, K. (2003). Site Preparation and Planting in a Shelterwood of Norway Spruce - Technical Feasibility and Seedling Mortality. *Scandinavian Journal of Forestry, 18*, 247-259.

Paper IV:
Suadicani, K., Hansen, L. P., & Heding, N. (2002). Natural Regeneration in a Shelterwood of Norway Spruce on Former Heathland. *Baltic Forestry, 8*, 15-20.

PAPER I

Operational Aspects of Two Thinning Methods in the Establishing of a Shelterwood in a Medium-aged Norway Spruce Stand

Kjell Suadicani and Tomas Nordfjell (2002)

Manuscript

Operational Aspects of Two Thinning Methods in the Establishing of a Shelterwood in a Medium-aged Norway Spruce Stand

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ABSTRACT

The thinning method is believed to influence the productivity as well as the quality of the harvesting work. In Scandinavia, marking of trees to be harvested is only done in exceptional cases. Instead the operator receives an instruction that describes how the thinning must be done. The aim of this study is to investigate the operational aspects (productivity, thinning quotient reduction in basal area, damage rate) of two thinning methods (termed row and selective thinning) in the establishment of a shelterwood in a medium aged Norway spruce stand. The harvesting was performed with a single-grip harvester operating from existing striproads (distance 15 m) parallel to the tree rows. Extraction with a forwarder was studied in the same stand. The two thinnings were more alike than expected. The thinning quotient was 0.9 and the reduction in basal area round 40% in both treatments. The time consumption for harvesting was larger in row than in selective thinning because row thinning was more difficult to perform when the harvester worked from striproads parallel to the tree rows. No difference in forwarding productivity was found. The damage rate was higher in row than in selective thinning. It is concluded that row thinning from striproads parallel to the tree rows has a negative influence on both productivity and quality of the work. This type of row thinning is difficult to perform because the tree rows are difficult to identify and because the trees are more difficult to reach. The operational aspects should be considered before a thinning method is chosen. Row thinning should preferably be carried out either by driving on removed rows or from striproads perpendicular to the tree rows.

Keywords: stem-damages, extraction, forwarder, harvesting, productivity, row thinning, selective thinning, single-grip harvester, stem-injuries, thinning pattern, time study.

INTRODUCTION

Norway spruce (*Picea abies* (L.) Karst.) is the most common tree species in northern and central Europe. It has been planted far beyond its natural range as for example on the former heath areas in western Denmark (Schmidt-Vogt 1987). Norway spruce has several advantages in these plantations on poor soil such as easy regeneration by planting after clearcutting, rapid juvenile growth and good timber quality. However some disadvantages have become apparent. The older stands are susceptible to windthrows, and root rot (caused by the fungus *Heterobasidion annosum* (Fr.) Bref.) has become more and more common. Because of the disadvantages objectives have been set to transform part of the heath plantations into mixed forests mainly of native broad-leaved species (Anon. 1994, Clausen 1995). Regeneration by clearcutting and replanting is not suitable for the introduction of species such as beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.), but under a shelterwood it is possible. However, in the windy climate of western Denmark fully-grown shelterwoods are often subject to windthrows. Less tall stands are more wind-resistant, and therefore early shelterwood regeneration (height <15 meters) has been proposed (Løfting 1949, Oksbjerg 1951, Henriksen 1971, Neckelmann 1995).

The harvester-forwarder system is used for almost all softwood harvesting in Scandinavia. The system has been analysed in detail with most efforts laid in studies of single-grip harvester productivity (Brunberg et al. 1989, Fjeld 1992, Fjeld 1994, Westerberg et al. 1996, Lageson 1997, Eliasson et al. 1999, Hånell et al. 2000). The mechanisation and the rationalisation of the forestry administration in the Nordic countries has led to that the traditional marking of trees for felling in thinnings has been replaced by tree selection performed by the machine operator based on a thinning instruction.

Establishing shelterwoods in stands planted in rows can be done in two principally different ways, row or selective thinning. Row thinning is defined as total removal of a proportion of the rows in some sequence, while selective thinning can be described as removing a proportion of the trees in every row, according to some individual selection criteria. Selective thinning is preferred if specific post stand characteristics or specific characteristics of the harvested trees are sought (thinning from below, thinning from above, thinning for quality etc.). Row thinning is preferred if accessibility to the stand is given priority for example for facilitating site preparation (Pregent 1998).

Establishing striproads is the most common type of row thinning, and the harvester operates from the striproad as it is established. This type of row thinning is efficient because it is easy to harvest trees directly in front of the harvester. If row thinning is to be done in stands where the distance between the tree rows is small, the most common solution is to use a very narrow machine or to remove two adjacent tree rows. Row thinning can also be performed the same way as selective thinning, which means that the harvester is operating from already established striproads, wide enough to drive on. This is not very common, but it can be relevant if shelterwood establishment is to be followed by site preparation with narrow drawn implements.

All thinning operations cause some damage to the remaining stand. The damage rate for single-grip harvesters in thinnings and in shelterwood establishments has been decreasing (Fröding 1992). In recent studies the proportion of damaged trees has been only 3% (Westerberg et al. 1996, Sirén 2001). Siren (2001) found variation between operators and a clear correlation between high productivity and low frequency of damaged trees. Fröding (1992) found that most damages occurred during processing (90%) while as much as 60% occurred during felling in Siren's study. Extraction also results in damages. Most of them (up to 80%) are made during loading (Nilsson 1985).

The aim of this study is to investigate the operational aspects (productivity, thinning quotient reduction in basal area, damage rate) of two thinning instructions (row and selective thinning) in the establishment of a shelterwood in a medium aged Norway spruce stand. The harvesting was performed with a single-grip harvester operating from existing striproads (distance 15 m) parallel to the tree rows. Extraction with a forwarder was studied in the same stand.

MATERIALS AND METHODS

The study area was a 50 year old Norway spruce stand (4.1 ha) on a poor sandy soil located in north-western Denmark (56° 30'N, 8° 22' E). Terrain conditions for the site were class 1 for bearing capacity, surface evenness and ground slope where class 1 represents very easy conditions and 5 very difficult conditions (Anon. 1991).

The stand was originally planted in rows with a spacing of approximately 1.4 m between and within the rows. Some silver fir (Abies alba Mill.), grand fir (Abies grandis Lindl.), Scots pine (Pinus silvestris L.) and larch (Larix decidua Mill.) were found in the stand, but 95% of the trees were Norway spruce.

Table 1: Stand data.

	Treatments			
	Operator 1 Row thinning	Operator 2 Row thinning	Operator 1 Selective thinning	Operator 2 Selective thinning
N_1(ha^{-1})	991	1088	953	975
D_{g1} (cm)	17.6	16.7	18.0	16.6
G_1(m^2 ha^{-1})	24.0	23.8	24.3	21.1
H_{g1} (m)	14.0	13.7	14.2	13.7
V_{s1} (m^3 ha^{-1})	182	178	186	157
N_2 (no. ha^{-1})	417	508	425	433
D_{g2} (cm)	16.3	15.9	17.2	15.3
G_2 (m^2 ha^{-1})	8.7	10.1	9.8	8.0
H_{g2} (m)	13.6	13.4	13.9	13.2
V_{s2} (m^3 ha^{-1})	65	74	74	58
V_{m2} (m^3 ha^{-1})	57	65	65	51
N_3 (ha^{-1})	574	580	528	541
D_{g3} (cm)	18.4	17.4	18.7	17.6
G_3 (m^2 ha^{-1})	15.3	13.7	14.5	13.2
H_{g2} (m)	14.3	14.0	14.4	14.0
V_{s3} (m^3 ha^{-1})	117	104	112	100

Symbols according to IUFRO standard (Anon. 1965 extended by Holten-Andersen 1989):

d:	Single tree diameter at breast height
h:	Single tree height
d/h:	Pair-wise diameter/height measurements
g:	Single tree basal area at breast height
v:	Single tree volume
N:	Number of trees per ha
D_g:	Mean basal area diameter at breast height
H_g:	Height referring to mean basal area diameter at breast height
V_g:	Total stem volume referring to mean basal area diameter at breast height
G	Basal area per ha
V_s:	Total stem volume per ha
V_m:	Merchantable volume per ha
Subscripts following symbols:	
1:	Before thinning
2:	In thinning
3:	After thinning

Striproads had been established, and the stand had been selectively thinned twice before the study, which had reduced the stand density from about

4000 to about 1000 trees per ha (N_1 according to symbols in Table 1). A main hauling road (5 meters wide) perpendicular to the rows and 26 striproads (4 meters wide, spaced 15 meters apart) parallel to the rows divided the stand into 54 plots, approximately 0.08 ha each consisting of approximately 9 tree rows. The stand was divided in four parts where row thinning and selective thinning as well as the effect of the two operators was studied (Fig. 1).

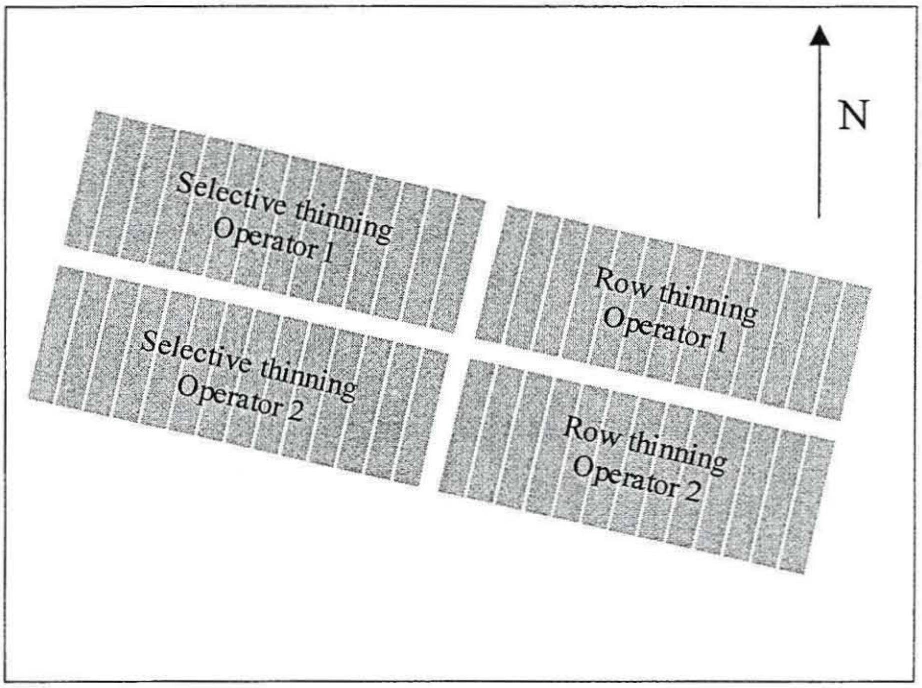

***Figure 1.** Study area and treatments.*

In selective thinning, the instruction was to leave 50-60% of the most vigorous trees uniformly spaced. In row thinning, the instruction was to remove every second tree row in order to obtain easy passage for site preparation implements (normally row 2 and 4 according to Fig. 2). A tree row was not to be removed, if this would cause larger gaps (i.e. more than 6×6 meters) in the stand structure. If so, the adjacent tree row should be removed (shifting row for a distance), still having in mind easy passage for site preparation implement. In both treatments dead, dying, recessive or damaged trees should be removed irrespective of their location, and trees of other species than Norway spruce should be preserved if possible. 2.2 meter saw logs and 3.0 meter pulpwood should be produced. Saw logs should have a minimum top diameter of 10 cm, be straight and without defects. Pulpwood should have a minimum top diameter of 7 cm and contain no rot. Treetops should be placed on the striproad because the shelterwood establishment should be followed by site preparation and planting.

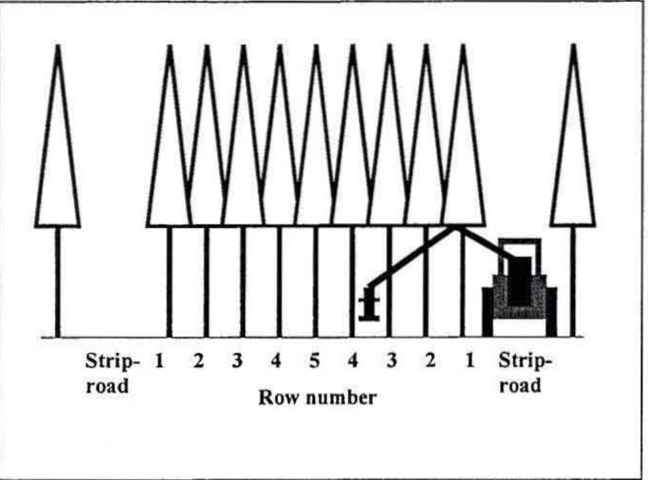

Figure 2. *Row numbers.*

Both methods should result in a density of approximately 550 trees per ha after thinning.

Before establishing the shelterwood, d_1 (Table 1) were measured in samples (1141 trees), while d_1/h_1 was measured on 39 trees. After establishing the shelterwood d_3's were measured on all (2284) shelter trees and d_3/h_3 was measured on 159 trees. The harvested trees were counted during the time study and d_2's were registered on 820 of the 1818 harvested trees. No d_2/h_2 were measured on harvested trees. A diameter/height function built on the same model as Näslund (1936) was estimated on the basis of all d/h ($h=(d\times(1.20+0.360\times d)^{-1})^3+1.3$). v_{s2} was calculated from a standard total stem volume function (Madsen & Heusèrr 1993). The harvester head measured the merchantable volume (v_{m2}) during harvesting.

The harvesting was done with a Silvatec 656 TH single-grip harvester (Table 2) driving on the striproads parallel to the rows. Extraction was carried out with a Valmet 820 forwarder (Table 2). Saw logs were extracted first, followed by pulpwood. Saw logs were loaded in two tandem stacks on the forwarder in order to double the volume of each load. The harvesting was carried out between the 20th and the 22nd and the extraction between the 26th and the 28th of May 1997.

Table 2. *Machine specifications.*

Harvester: Silvatec 656 TH
Engine type and power: Perkins 1006-T, 114 kW
Weight: 11000 kg
Width: 2.5 m
Length: 6.3 m
Crane type and reach: Silvatec 7570, 7.0 m.
Harvester head type and weight: Silvatec 445, 750 kg
Inlet diameter: 50 cm
Delimbing diameter: 5-45 cm
Forwarder: Valmet 820
Engine type and power: Valmet 420 DW, 80 kW
Weight: 9300 kg
Width: 2.5 meter
Length 7.9 meter
Load area: 3.4 m^2
Max load: 8500 kg
Crane type and reach: Cranab 580, 5.4 m
Grapple type and area: Cranab 280, 0.28 m^2

Productive work time (Björheden 1995) was recorded in a cumulative time study using SIWORK-3 software on a Husky Hunter computer (Rolev 1988). In the harvesting study the unit of observation was the individual tree, and in the forwarding study it was the individual load. In the harvesting study the productive work time ($PW_{Harvest}$) was divided into processing (PROC), positioning (POS), moving (MOVE) and preparation (PREP). In the forwarding study the productive work time ($PW_{Forward}$) was divided into loading (LOAD), driving while loading (DRIVE), adjusting the load (ADJUST), unloading (UNLOAD), driving with full load (FULLDRIV), and driving without load back into the stand (EMTYDRIV) (Table 3).

The harvesting time-study results have been standardised to fixed conditions (N_2=450, d_2=15.8) through the use of covariates. In the harvesting study the analysis of PROC and POS has been done on 820 single tree observations. For PROC d_2 has been used as covariate. For POS d_2 was also tested as covariate, but it had no sifnificant effect. MOVE per ha was calculated on the basis of 46 observations each representing MOVE along a striproad (24 observations in row thinning and 22 in selective thinning). The areas were calculated as half the sum of the two plot areas on each side of the striproad. Analysis of MOVE per ha was done using N_2 as covariate. After standardising to fixed conditions (N_2=450) MOVE per tree was calculated as MOVE per ha divided by 450. PREP per ha was calculated and analysed the same way as MOVE, but without covariate.

Table 3. Work elements.

Operation	Work element and abbreviations	Description and demarcations	Priority
Harvesting	Processing (PROC)	Starts when the boom reaches the tree and the saw begins to fell the tree and ends when the harvester head releases the treetop on the striproad and the boom starts to move for the next work element.	1
	Positioning (POS)	Starts when the harvester head releases the treetop, slash etc. and when the boom moves towards the next tree and ends when the saw begins to fell the tree.	1
	Preparation (PREP)	Starts when harvester head releases the treetop and the boom is used for preparation purpose and ends when the boom moves towards the next tree.	1
	Moving (MOVE)	Starts when the treetop, slash etc. is released and ends when the wheels stops rolling	2
Extraction	Loading (LOAD)	Starts when the grapple starts to move for loading and ends when the grab has placed the assortments on the load and moves for the next work element.	1
	Adjusting the load (ADJUST)	Starts when the grapple starts to move for adjusting the load and ends when the grapple starts to move for the next work element.	1
	Driving while loading (DRIVE)	Starts when the grapple stops to move and the machine starts to move and ends when the forwarder stops and the grapple starts to move for the next work element.	2
	Unloading (UNLOAD)	Starts when the grapple starts to unload. Ends when the grab stops to move and the forwarder starts to drive.	1
	Driving with full load (FULLDRIV)	Starts when the grapple stops to move and the forwarder starts to drive out of the stand. Ends when the forwarder stops moving and the grapple starts to move for unloading.	2
	Driving unloaded (EMTYDRIV)	Starts when the grapple stops to move and the forwarder starts to drive into the stand. Ends when the forwarder stops moving, and the grapple starts to move for loading.	2

For the extraction the time consumption per m^3_m (merchantable volume) was calculated on the basis of data from 20 full loads (4 loads of pulpwood in row thinning, 6 loads of pulpwood in selective thinning, 6 loads of saw logs in row thinning, and 4 loads of saw logs in selective thinning). DRIVE has been adjusted proportional to N_2 to eliminate the effect of thinning intensity ($DRIVE_{adjusted}=DRIVE \times N_2/450$). Extraction distance was standardised to 150 m on forest roads and 100 m on striproads/main hauling roads on the basis of a linear regression.

After harvesting and forwarding, the number of injured shelter trees was registered in all 54 plots. All visible damages exposing the xylem were registered irrespective of their size, according to Fröding (1983). Damaged trees were classified in two groups: (1) visible root-damages and damages lower than one meter above the ground and (2) damages one to five meters above the ground.

All analyses have been carried out in SAS statistical package version 6.12 (Anon. 1989a, 1989b). Models have been tested for outliers, influential values, and constant variance in the guided data analysis module. Transformations have been made where appropriate in order to obtain normal distributions, but all mean values are calculated on untransformed data. Typically, variance of the residuals in time-study data is non-constant, and is characterised by the "right opening megaphone distribution" (Weisberg 1985) i.e. there is a greater variation associated with the larger observations than with smaller. The logarithmic transformation has been found to be suitable for time study data giving the transformed observations a normal distribution and a constant variation.

In the economical analyses workplace time was used as time basis. For both harvesting and forwarding workplace time was calculated as 1.49 multiplied with the productive work time (Samset 1995). The productive time is considered equal to E_0 (Effective work-time according to Anon. 1978). Prices for saw logs and pulpwood were assumed to 38 and 23 Euro m^{-3}_{m} respectively. Machine costs was set to 119 Euro h^{-1} for the harvester and 81 Euro h^{-1} for the forwarder (Andersen, pers. comm. 1999).

RESULTS

In total 1818 trees were harvested giving 143 m^3_m saw logs and 87 m^3_m pulpwood. The ratio between V_{m2} and Vs2 was calculated to 87.5% on basis of the total merchantable volume and the total stem volume (Table 1). $PW_{Harvest}$ was studied over 17.0 hours and $PW_{Forward}$ over 21.3 hours.

The reduction in basal area was around 40 % area and the thinning quotient was approximately 90% in both row thinning and selective thinning (Table 1).

Before thinning the density of trees decreased with increasing distance from the striproad. In selective thinning the degree of thinning also decreased with increasing distance from the striproad, and therefore selective thinning resulted in quite a uniform distribution of shelter trees. In row thinning the degree of thinning was strongest in tree row 2 and 4 in accordance with the instruction. Row thinning was more strictly practised in row 2 than in row 4, and row thinning resulted in a high density of shelter trees in tree row 1 (Fig. 3).

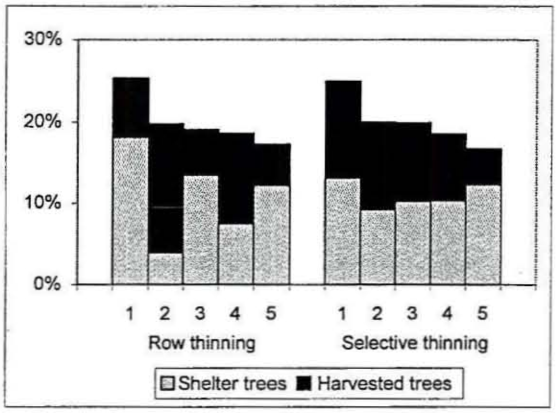

Figure 3. *Proportion of trees in rows. Row 1 is closest and row 5 is farthest away from the striproad.*

After standardisation, $PW_{Harvest}$ was 10% shorter in selective thinning than in row thinning because PROC and POS were shorter. No significant difference was found between the two operators except that operator 1 used more time for PREP (Table 4). Both PROC and POS took a longer time if trees were harvested far away from the striproad, and in all tree rows PROC and POS took more time in row thinning than in selective thinning (Fig. 4). MOVE per ha was strongly correlated to N_2 and no significant difference between row thinning and selective thinning could be found (Table 4). The total number of working positions per ha (the number of the work element MOVE per ha) was also strongly correlated with N_2 while MOVE per position did not seem to be correlated with N_2.

A full load of saw logs and pulpwood consisted of 10.5 m^3_m and 6.6 m^3_m (m^3 merchantable volume) respectively for both treatments. There was no significant difference in $PW_{Forward}$ between the two treatments, but significant differences were found between the two assortments. 73% of the time consumption was used for LOAD, DRIVE and ADJUST and 27% for FULLDRIV, EMTYDRIV and UNLOAD. LOAD and DRIVE took more time for pulpwood, and ADJUST took longer for saw logs (Table 5). A grapple contained 0.16 and 0.11 m^3_m saw logs and pulpwood respectively when loading. Corresponding values for unloading was 0.42 m^3_m and 0.50 m^3_m. On basis of the observations of FULLDRIV and EMTYDRIV two regressions were made (Table 5). The speed on forest roads was estimated to 11 km h^{-1} with load and 13 km h^{-1} without load, and the speed at the striproad was estimated to 4 km h^{-1}, both with and without load.

Table 4. *Harvesting productive work time in cmin tree^{-1} (% of total time).*

	Treatments			
Work element	Operator 1 Row thinning	Operator 2 Row thinning	Operator 1 Selective thinning	Operator 2 Selective thinning
PROC	31.9 b*	32.7 b	29.2 a	28.8 a
POS	12.4 b	14.1 c	11.0 a	11.1 a
MOVE	6.6 a	7.6 a	6.2 a	6.5 a
PREP	2.1 b	0.3 a	2.1 b	0.3 a
TOTAL	53.0 b	54.7 b	48.5 a	46.7 a
	Mean values in row thinning		Mean values in selective thinning	
PROC	32.3 (60)		29.0 (61)	
POS	13.3 (25)		11.1 (23)	
MOVE	7.1 (13)		6.4 (13)	
PREP	1.2 (2)		1.2 (3)	
TOTAL	53.9 (100)		47.6 (100)	

*In each row different letters indicate significant difference at p<0.05 level.

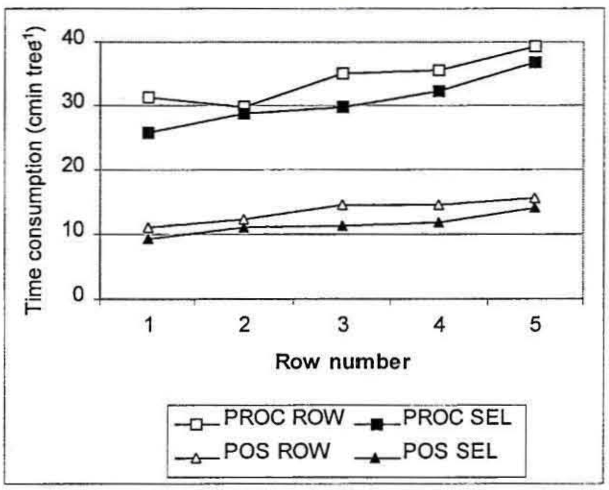

Figure 4. *Time consumption for processing and positioning for the harvester. Row 1 is closest and row 5 is farthest away from the striproad.*

The only difference in the economic analysis is in the harvesting costs (Table 6). The reason is that no differences in mean tree size of the harvested trees, in the distribution of assortments, or in $PW_{Forward}$ was found between the treatments. This result would not be expected if the thinning instruction was followed more strictly. It could also not be expected in less uniform stands because larger variation in tree size should affect the thinning quotient.

Table 5. *Forwarding productive work time in cmin m^{-3}_{m} (% of total time).*

Work element	Treatment			
	Saw logs Row thinning	Saw logs Selective thinning	Pulpwood Row thinning	Pulpwood Selective thinning
LOAD	230 a*	213 a	267 a	258 a
DRIVE	79 a	72 a	113 b	93 ab
ADJUST	97 b	86 b	46 a	42 a
UNLOAD	88 b	81 b	62 a	62 a
FULLDRIV**	30	30	48	48
EMTYDRIV**	25	25	40	40
TOTAL	550 a	507 a	577 a	544 a
	Mean values for Saw logs		Mean values for Pulpwood	
LOAD	222 (42)		263 (47)	
DRIVE	75 (14)		103 (18)	
ADJUST	92 (17)		44 (8)	
UNLOAD	85 (16)		62 (11)	
FULLDRIV**	30 (6)		48 (9)	
EMTYDRIV**	25 (5)		40 (7)	
TOTAL	529 (100)		561 (100)	

* In each row different letters indicate significant difference at $p<0.05$ level.
** Standardised to a driving distance of 150 m on forest roads and 100 m on striproads.
Regressions: FULLDRIV = (86.59 + 0.552 * FR + 1.498 * SR)/load size
EMTYDRIV=(51.68 + 0.458 * FR + 1.468 * SR)/load size
FR = meters on forest road, SR = meters on striproads
Load size for saw logs: 10.5 m^3_m
Load size for pulpwood: 6.6 m^3_m

Table 6. *Income and costs at roadside (Euro ha^{-1}).*

		Row thinning	Selective thinning
Income	Saw logs	1333	1333
	Pulp wood	495	495
	Total	1828	1828
Costs	Harvesting	721	644
	Extraction LOGS	373	373
	Extraction PULP	242	242
	Total	1337	1259
Net income		491	568

The selective thinning seems to result in lower damage rate below one meter especially for operator 2. Row or selective thinning or operator did not seem to affect damage rate from one to five meters above ground level (Fig. 5).

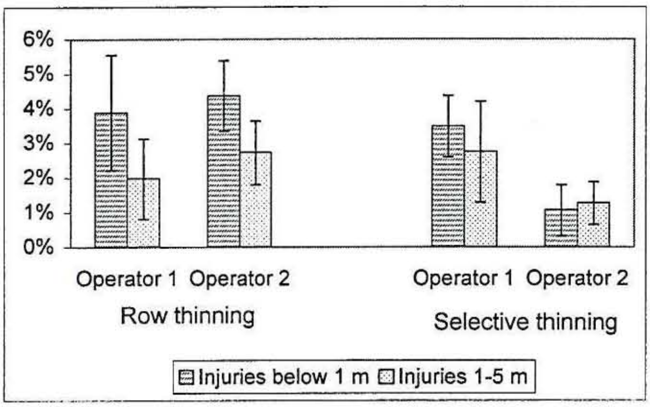

Figure 5. *Proportion of damaged shelter trees with 95% confidence intervals below 1 m above the ground and 1-5 m above the ground.*

DISCUSSION

It is recommended to establish a shelterwood by at least two thinnings (Neckelmann 1995). The shelterwood establishment in this study can be considered as the second thinning in the process because the initial thinning was done five years earlier.

It was expected that row thinning would have resulted in a thinning quotient near one and selective thinning round 80-90%. Anyhow the results showed no difference in thinning quotient between the two treatments. The explanations are that row thinning was not stringently adhered to, and that large trees often stand isolated and therefore are preserved to a higher degree than small trees. The operators maybe prefer to remove small trees in row thinning because a tree represents an obstruction for site preparation irrespective of its size. Another explanation could be that the operators are so used to thin from below that they do it automatically, also in row thinning.

PROC increases with increasing distance from the tree to the striproad because the tree must be pulled out to the striproad. POS also increases with increasing distance from the striproad to the tree because it takes more time for the boom to move the longer distance. One explanation of the higher time consumption in row thinning is therefore that the trees in average were harvested farther away from the striproad. Another explanation is the higher number of shelter trees in tree row 1 for row thinning (Fig. 3), because these trees obstructed boom operations the most.

The increase in MOVE per ha with increasing thinning strength shows that MOVE was not only determined by the driving distance, but also connected with the harvesting operation (parallel to POS). In other words one can say that one part of MOVE per ha was used to move the harvester on the striproads, and the other part was used for micropositioning the machine in order to harvest a tree.

LOAD depends on the volume per grapple and therefore LOAD is faster for saw logs than for pulpwood. When unloading, the opposite is true (more volume in a grapple of pulpwood) because of the longer lengths. DRIVE depends on the density (m^3ha^{-1}), and was therefore shorter for saw logs than for pulpwood. ADJUST includes additional time for loading tandem stacks on the forwarder, and therefore ADJUST is more time consuming for saw logs. On the other hand the tandem stacks double the load, which halve FULLDRIV and EMTYDRIV. The size of the load does not seem to affect speed, but EMTYDRIV is faster than FULLDRIV.

The damage rate was acceptably low compared with similar studies (Fröding 1992, Westerberg et al. 1996, Sirén 1999) taking into consideration that the damage rate was a result of both harvesting and extraction. The present study showed more damages in row thinning compared to selective thinning below 1 m from the ground. Fröding (1982) examined the spatial distribution of injuries in thinning. He found that the injury rates often decrease as the distance from the striproad increases. This could explain the higher damage rate in row thinning simply because there were more shelter trees left in row 1. The larger number of damages in row thinning can also be attributed to the different distribution of shelter trees for the two treatments. The shelter trees are quite uniformly spaced after selective thinning, which means that there is approximately four meters between the trees. The average distance between the shelter trees in row thinning depends on the orientation. The distance between the shelter trees in the tree rows is smaller than average and the inter-row distance is larger than average. Because the trees are felled perpendicular to the tree rows, the spacing between the trees in the tree row determines the space for felling and thereby the level of damages.

In both treatments the operator should remove trees with obvious damages, providing that it did not result in an unacceptably large gap in the canopy. The work pattern in selective thinning might makes it easier to remove damaged trees, because the damaged trees can be reached more easily.

Both operators preferred to do selective thinning. The reason might lie in this being routine practice, but the operators also pointed out that the single-grip harvester is designed in a way that the operator can see the whole tree, allowing him to asses its quality. The view from the cabin also gives the operators a good picture of the distribution of the trees, but the operators can not easily identify the specific tree rows, because their line of sight is perpendicular to the rows. Therefore they often had to stand up or lean forward to identify the tree rows in row thinning.

Selective thinning must be preferred from a stand vigour aspect, because vigour is a more dominant selection criterion in selective thinning than in row thinning. In a vigorous stand like the one studied almost all trees are acceptable shelter trees, but in spite of this row thinning could not be practised strictly. In less vigorous stands row thinning will be unacceptably restrictive. If row thinning had been done in earlier thinnings, it could have been applied more strictly.

An alternative way to do row thinning is to drive on striproads perpendicular to the rows (Fig. 6 Harvester no. 2). This would make it easy for the operator to identify the tree rows and remove each second row. The accessibility of the harvester head in the stand would be improved, and the felling would be parallel to the rows. This would increase productivity and simultaneously reduce the number of injuries.

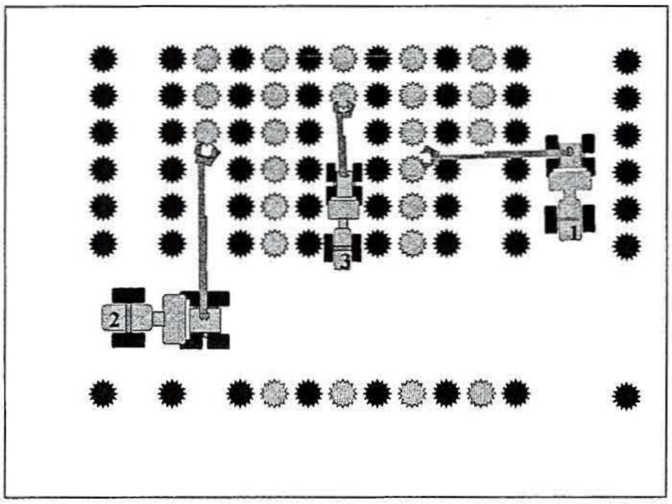

Figure 6. *Row thinning can be performed from striproads parallel to the rows (1), or from striproads perpendicular to the rows (2), or with a narrow harvester driving in the stand (3).*

Row thinning could alternatively be carried out using a more compact harvester being able to drive in a 2.2-2.4 m wide corridor (e.g. Sambo Rosenlew 1046X) (Fig. 6 harvester no. 3). There are also forwarders narrow enough to drive in such a corridor (Nordfjell et al. 2001). Productivity would increase because of decreased POS. This way of doing row thinning could be of interest as younger spruce plantations are often established with an inter-row spacing of 1.7 meters, providing a 2.8-3.0 m wide corridor after row thinning. That space makes it more realistic to drive machines there.

The way row thinning has been carried out in this study has a negative influence on the harvesting productivity and also on the damage rate, but row thinning can be preferred if the disadvantages are compensated by advantages for the site preparation. The final conclusion must be that the two treatments can be combined. The instruction could be to leave vigorous trees on the area uniformly spaced, at the same time being aware of the accessibility requirements of site preparation equipment. Other ways of executing row thinning e.g. driving on the removed rows or driving on striproads perpendicular to the present striproads are expected to give higher productivity and lower damage rate than the method used in this study.

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PAPER II

Fuel Chips Production in a Medium-aged Norway Spruce Stand

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Manuscript

Fuel Chips Production in a Medium-aged Norway Spruce Stand

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ABSTRACT

The so-called terrain-chipping system is widely used for thinning of young stands in Denmark. Because of low pulpwood prices, the system is also relevant in older stands, but problems have occurred on handling the larger trees in an upright position. Possibilities of harvesting round wood and fuel chips simultaneously (integrated harvesting) have also shown up. The felling operation is critical because the felling operation determines the chipping productivity and the number of damages on the remaining trees. The aim of the study is to analyse and compare three systems of whole tree chipping and one system of integrated harvesting in a medium-aged stand of Norway spruce. The whole-tree systems had different felling operations (1) Motor manual felling, (2) felling and bunching at the striproads with a feller-buncher and (3) felling in herringbone pattern with a single-grip harvester. The integrated harvesting (4) was also performed by felling in herringbone pattern with a single-grip harvester, but the felling included production of a piece of saw log in the butt end when possible. All chipping was performed in the stand. It was found that chipping productivity was strongly dependent on easy feeding of the trees. Motor manual felling was cheaper than mechanical felling and bunching, but the bunching improved the chipping productivity so much that it fully made up for the extra felling costs. Integrated harvesting improved the income compared with whole tree chipping, but the net income was lower than for the whole tree chipping with motormanual felling or felling and bunching with a feller-buncher. It is concluded, that easy feeding is essential for chipping productivity and system economy. Integrated harvesting is considered inferior to either whole tree chipping or short wood harvesting at least in the way it was performed in this study. An alternative could be to use a combined harvester/forwarder for integrated harvesting.

Keywords: harvesting costs, felling methods, forest operations, integrated harvesting, productivity, time consumption, TP-960 chipper, whole-tree chipping, work-study.

INTRODUCTION

Conventional first or second thinning in plantations of Norway spruce (*Picea abies* (L.) Karst.) most often hardly yield any income for the forest owner, especially if root and butt rot (e.g. Heterobasidion annosum (Fr.) Bref. and Armillaria mellea (Vahl ex. Fr.) Kumm.) are present. Assortments that can be produced from those kinds of stands are poorly paid, and the productivity is low because of the small dimensions and low yield (e.g. Hudson 1999, Bouvarel 1995, Syversen & Dale 1995). Fuel chips are relatively well paid in Denmark because of taxes on fossil fuels, and therefore chip harvesting is an alternative to conventional thinning in young stands and stands of low quality (Heding 1990). The productivity in chip harvesting is less dependant on single tree dimension and quality because it includes multiple tree handling, and because the whole tree is utilised.

Since around 1980 a system for harvesting fuel chips has been used in Denmark for thinning of young, even-aged softwood stands (Kofman 1993, Hansen 1995). The system includes the following four steps. (1) Trees are felled in the spring and left to dry for one summer. (2) A chipper carrying a container and driving on the striproads processes the trees. (3) The chips are reloaded into a tractor-drawn chip container transporting it to the roadside and unloading the chips into truck-containers (4) The chips are transported by truck either to a heating plant or to storage (Fig. 1). This system, often termed terrain-chipping, has been tested or been in commercial use in several other countries mostly in northern Europe (Dreiner et al. 1993, Hakkila 1990, Kofman 1990, Person & Brunberg 1994, Verkasalo 1994).

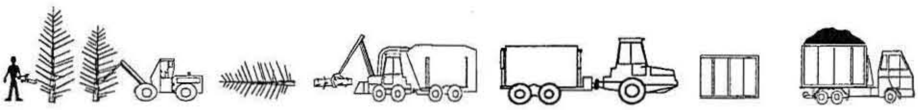


***Figure 1.** The Danish chip harvesting system (after Hansen 1995).*

In recent years the chip system has been implemented in older stands than before because of the low prices on pulpwood. In stands with diameter at breast height up to approximately 12 cm the trees are felled by a feller-buncher that easily lifts the trees in an upright position for placement alongside the striproad. This is difficult in stands with bigger trees because of the weight, especially for trees far away from the striproad. An alternative is motormanual felling in lines as done when striproads are established. This method demands row thinning because the chipper must be able to drive on the removed tree rows to be able to feed the trees. Another solution is mechanically felling without handling of the trees in an upright position. If a front-fed chipper is used, the trees must be felled in herringbone pattern with an acute angle. If a side-fed chipper is used, the trees must be felled perpendicular to the striproads.

Chipping is the key operation in the system, because of the costs. Front-fed chippers are the most common in Denmark, because they can be used for both row and selective thinning. Easy in-feed is essential for chipping productivity, and it is therefore important that the felling results in trees properly arranged for chipping. The highest chipping productivity is expected in row thinning or if thinning is done with a feller-buncher that places the trees in lines at the striproad. Lower productivity is expected if the felled trees are placed in herringbone pattern for chipping, or if a side-fed chipper is used (Kofman 1988a). In several tests the Fendt Favorit 614 LSA/TP-960 chip-harvester (Fig 2) has shown to be quite cost effective mainly because the costs are lower than most other chip-harvesters (Kofman 1988a, Kofman 1993, Suadicani & Pedersen 1995), and it has also been tested in Germany (Dreiner et al. 1993), France (Nabos et al. 1984) and in Great Britain (Mitchell et al. 1989).

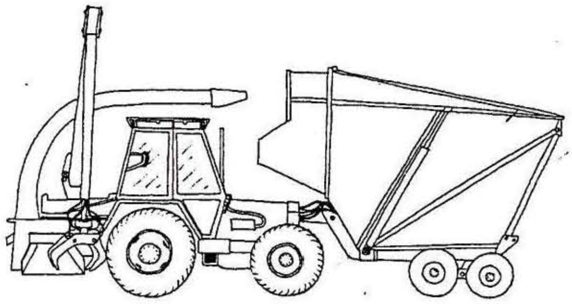


Figure 2. *The Fendt/TP-960 chip harvester.*

Chipping and terrain-transportation is serial coupled work, and therefore the productivity is determined of the slower of the two machines. A proper design of the work therefore requires that the two machines have approximately the same productivity. If this is not the case, one machine will have interference time.

In medium-aged stands two or more assortments are often produced: a high-quality assortment in the butt end and a low quality assortment in the top end or from trees of low quality. Two round wood assortments are normally produced simultaneously without significant additional costs. Production of a round wood assortment and fuel chips (integrated harvesting) are often expensive because several machines must operate on the same area (Kofman 1988b). Integrated harvesting is especially relevant if the butt end is of high quality and if a high proportion of wood is not suitable for production of round wood assortments. If felling is done with a harvester, it is possible to cut off a piece of roundwood, and maybe improve the placement of the tops for chipping.

The aim of the study is to analyse and compare three systems of whole tree chipping and one system of integrated harvesting in a medium-aged stand of Norway spruce. The emphasis is put on different felling systems, the influences on the chipping operation and the overall system productivity and economy.

MATERIALS AND METHODS

The study area was a 50 year old Norway spruce stand (4.06 ha) on a poor sandy soil located in north-western Denmark (56° 30'N, 8° 22' E). Terrain conditions for the site were class 1 for bearing capacity, surface evenness and ground slope in which class 1 represents very easy conditions and 5 very difficult conditions (Anon. 1991). The stand was originally planted in rows with approximately 1.4 meters space between and within the rows.

Before the study, a striproad system had been established, and two selective thinings had reduced the density to about 1000 trees per ha (N_1 according to symbols in Tab. 1). A main hauling road (5 meters wide) perpendicular to the rows and 23 striproads parallel to the rows (4 meter wide, spacing 15 m) divided the stand into 48 plots each approximately 0.08 ha. Each plot consisted of approximately 9 tree rows.

The four treatments were: (1) Trees were felled motormanually and placed in lines followed by whole-tree chipping (MOMA). (2) Felling and bunching the trees in lines on the striproads followed by whole-tree chipping. (3) Felling in herringbone pattern followed by whole-tree chipping (HARV) and (4) Felling in herringbone pattern and cutting off a 4,2 m butt log if the tree met the quality requirements (straight growth, no rot and top diameter more than 12 cm) and chipping of the tops (HARV-INT)(Tab. 2).

A skilled forest worker with a chainsaw did the felling in MOMA. The instruction was to remove tree row 4 counted the striproad. A row was not to be removed, if this would cause larger gaps (i.e. more than 6×6 m) in the stand structure. In this case the adjacent row should be removed in order to obtain easy passage for the chipper and for site preparation implements. Dead, dying, unhealthy or damaged trees should be removed irrespective of their location. A Silvatec 854 feller-buncher did the felling in FEBU. The instruction was the same as for felling in MOMA except that tree row 2 counted from the striproad should be removed. A Silvatec 656 TH harvester did the felling in HARV and HARV-INT. The instruction was to remove 45% of the trees leaving approximately 550 of the most vigorous trees uniformly spaced. The angle between the striproad and the felled trees

Table 1. *Stand data.*

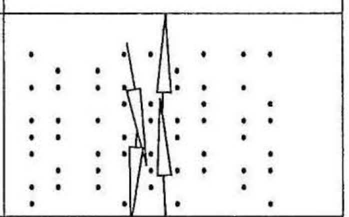
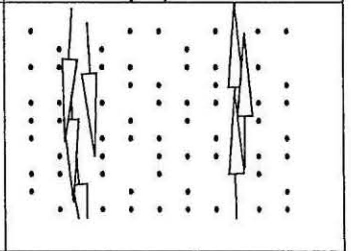
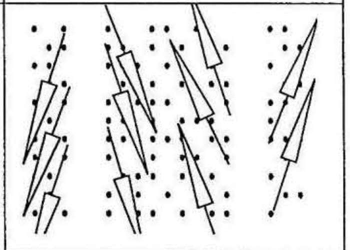
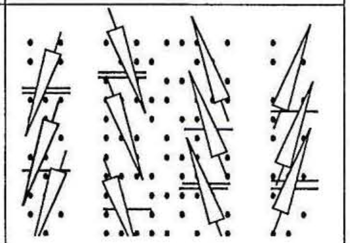
System	MOMA and FEBU*	HARV	HARV-INT
N_1 (ha^{-1})	1039	875	1017
D_{g1} (cm)	15.9	16.6	17.0
H_{g1} (m)	13.4	13.7	13.8
G_1 (m^2 ha^{-1})	20.6	19.1	23.1
V_1 (m^3 ha^{-1})	151	141	173
N_2 (ha^{-1})	474	334	454
D_{g2} (cm)	15.2	15.5	16.4
H_{g2} (m)	13.1	13.2	13.6
G_2 (m^2 ha^{-1})	8.6	6.4	9.5
V_2 (m^3 ha^{-1})	62	46	71
V_{2chips} (m^3_{loose} ha^{-1})	190	140	136
$V_{g2chips}$ (m^3_{loose} $tree^{-1}$)	0.40	0.42	0.30
$V_{2saw\ logs}$ (m^3_{solid} ha^{-1})	-	-	27
$V_{2saw\ logs}$ (m^3_{solid} $tree^{-1}$)	-	-	0.06
N_3 (ha^{-1})	565	540	540
D_{g3} (cm)	16.4	17.3	17.6
H_{g3} (m)	13.6	13.9	14.0
G_3 (m^2 ha^{-1})	12.0	12.7	13.6
V_3 (m^3 ha^{-1})	89	96	104

* Stand data were not separated for those two treatments.

Symbols according to IUFRO standard (Anon. 1965 extended by Holten-Andersen 1989):

Symbols:	
d:	Single tree diameter at breast height
h:	Single tree height
d/h:	Pair-wise diameter/height measurements
g:	Single tree basal area at breast height
v:	Single tree volume
N:	Number of trees per ha
D_g:	Mean basal area diameter at breast height
H_g:	Height referring to mean basal area diameter at breast height
V_{gchips}:	Volume of chips in trees having mean basal area diameter at breast height
G	Basal area per ha
V_{chips}:	Volume of chips per ha
Subscripts following symbols:	
1:	Before thinning
2:	In thinning
3:	After thinning

Table 2. System descriptions, machine specifications, and felling pattern.

System description (abbreviations)	Felling	Chipping	Terrain transport	Felling pattern
• Motormanual felling. • Chipping of whole-trees with a chip-harvester driving in the stand. • Terrain transport with a chip forwarder. (MOMA)	Chainsaw	Chip harvester: Fendt Favorit 614 LSA/TP-960 Engine type and power: MAN 122 kW Weight: 12000 kg Width: 2.2 meter Length: 12.0 m Crane type and reach: MOWI 2570 7 m Chip container: Spragelse 14 m^3_{loose}.	Chip-Forwarder: Fendt 308/Spragelse Engine type and power: Deutz 63 kW Weight: 5400 kg Width: 2.2 meter Length: 9.0 meter Chip Container: Spragelse 14 m^3_{loose}	
• Felling and bunching at the striproads with a feller-buncher. • Chipping of whole-trees with a chip-harvester driving at the striproads. • Terrain transport with a chip forwarder. (FEBU)	Feller-buncher: Silvatec 854 TH Engine type and power: Perkins 1004-T, 77 kW Weight: 10300 kg Width: 2,5 m Length: 6,5 m Crane type and reach: Silvatec 7570, 7.0 m. Felling head type: Kockums (modified)	As above	As above	
• Felling in herringbone pattern with a harvester driving at the striproads. • Whole-tree chipping with a chip-harvester driving at the striproads. • Terrain transport with a chip forwarder. (HARV)	Harvester: Silvatec 656 TH Engine type and power: Perkins 1006-T, 114 kW Weight: 11000 kg Width: 2.5 meter Length: 6.3 meter Crane type and reach: Silvatec 7570, 7.0 m. Harvester head type and weight: Silvatec 445, 750 kg	As above	As above	
• Felling in herringbone pattern with a harvester driving at the striproad (included cutting off saw logs). • Terrain transportation of saw logs. • Chipping of tree tops with a chip-harvester driving at the striproads. • Terrain transport with a chip forwarder. (HARV-INT)	As above	As above	As above and Forwarder: Valmet 820 Engine type and power: Valmet 420 DW, 80 kW Weight: 9300 kg Width: 2.5 meter Length 7.9 meter Load area: 3.4 m^2 Max load: 8500 kg Crane and grip type: Cranab 580/280 Reach: 5.4 meter Grip area: 0.28 m^2	

should not exceed 30°, and the herringbone pattern should be turned for each striproad permitting the chipper to drive forward and reverse on the area. The operators made the tree selection themselves, which is the norm in Scandinavia. The extraction of the butt logs in HARV-INT was carried out with a Valmet 820 forwarder. All chipping was done with a Fendt Favorit 614 LSA/TP-960 chip-harvester (Fig. 2). The chips were reloaded into a tractor for terrain transportation. All operators had several years of experience operating their machines.

The stand was divided into three parts (Fig. 3). In the 22 eastern plots MOMA and FEBU was carried out (Fig. 4). Note that row thinning is carried out in these plots. The next 14 plots were HARV, and the last 12 plots were HARV-INT.

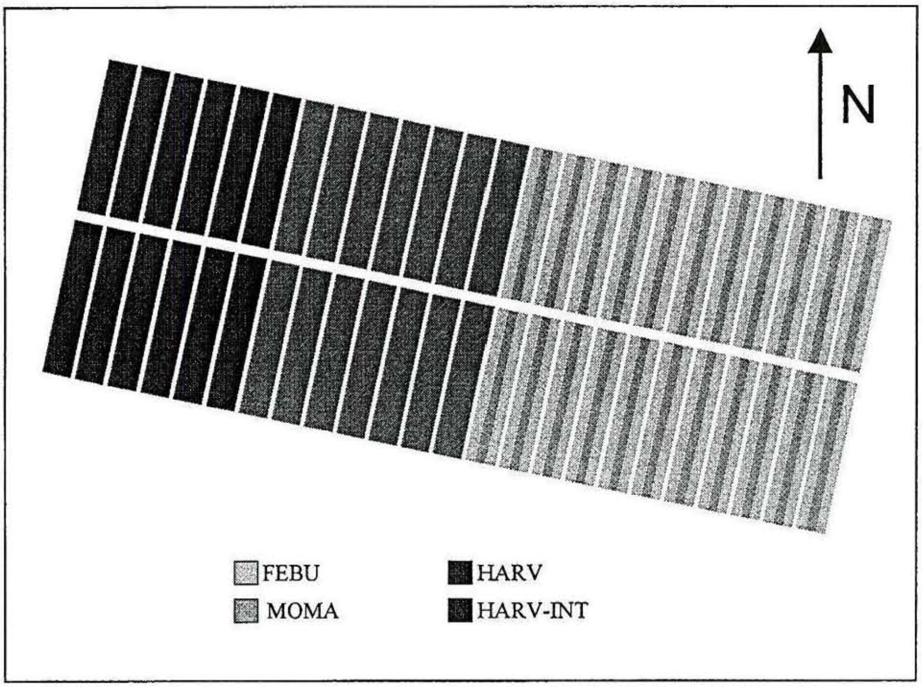


Figure 3. The study area.

Before establishing the shelterwood single tree diameter (d_1) was measured on 481 trees, while d_1/h_1 was measured on 40 trees. After establishing the shelterwood single tree diameter (d_3) was measured on all (2201) shelter trees and d_3/h_3 was measured on 144 trees. The number of felled trees was registered during felling, and single tree diameter (d_2) was registered on 342 of the 1055 time-studied trees. No d_2/h_2 were measured on harvested trees. A diameter/height function built on the same model as Näslund (1936) was estimated on basis of all d/h ($h=(d\times(1.20+0.360\times d)^{-1})^3+1.3$). Single tree chip volume functions (Suadicani 1996a) were used for calculating average chip volume per tree (V_{g2chip}). In HARV-INT average treetop chip volume was calculated from V_{g2chip} reduced by the volume of butt logs divided by a solid content factor of 0.35 (Anon. 1990).

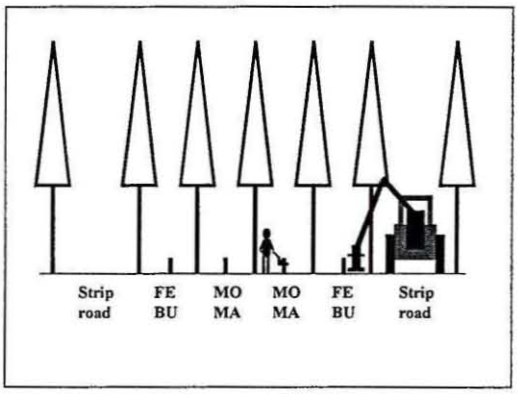


Figure 4. *Tree rows felled with a feller-buncher (FEBU) and rows felled motormanually (MOMA).*

One sample (3-4 litres) was extracted from each load for the assessment of chip quality according to Brüel & Sørensen (1987). The felling was carried out on the 25th and the 26th and the extraction of the butt logs on the 30th of June 1997. The chipping was done the 10th, 11th, 15th and 16th of September 1997. The weather in the drying period was excellent. June and July 1997 were warm and sunny, and August was the warmest month ever registered in Denmark. September 1997 was also dry, sunny and warm (Anon. 1998).

Productive work time (Björheden 1995) was recorded in cumulative time studies using SIWORK-3 software on a Husky Hunter computer (Rolev 1988). In the study of felling the productive work time ($PW_{Felling}$) was divided into felling (FELL), moving ($MOVE_{felling}$), and miscellaneous ($MISC_{felling}$). In the study of chipping the productive work time ($PW_{Chipping}$) was divided into chipping (CHIP), moving ($MOVE_{chipping}$) and miscellaneous ($MISC_{chipping}$)(Tab. 3).

The analysis of FELL was done on 342 single tree observations, and the results were standardised to fixed conditions (D_{g2}=15.8) through the use of individual covariate functions for each felling method. The analysis of $MOVE_{Fell}$ per ha was done on 35 observations representing felling along a striproad (15 observations in FEBU, 11 in HARV, and 9 in HARV) and 32 observations representing walking from one tree to the next (MOMA). Standardisation to fixed conditions (N_2=450) was done using N_2 as covariate factor. $MOVE_{Fell}$ per tree was calculated as $MOVE_{Fell}$ per ha divided by 450. $MISC_{Fell}$ was analysed the same way as $MOVE_{Fell}$, but without covariate.

Table 3. Work elements for felling and chipping.

Operation	Work element and abbreviations	Description and demarcations	Priority
Felling in MOMA	Felling (FELL)	Starts when the chain saw is speeded up and ends when the tree lands on the ground.	1
	Moving ($MOVE_{felling}$)	Starts when the tree lands on the ground and the forest worker walks towards the next tree. Ends when the chainsaw is speeded up for felling the next tree or when miscellaneous occurs.	2
	Miscellaneous ($MISC_{felling}$)	Any other time element included in the productive work time.	3
Felling in FEBU, HARV and HARV-INT	Felling (FELL)	Starts when the felling head (harvester head) releases the previous tree (top) or when the machine stops moving. Ends when the tree (top) is released on the ground.	1
	Moving ($MOVE_{felling}$)	Starts when the machine starts moving and ends when the machine stops moving.	2
	Miscellaneous ($MISC_{felling}$)	Any other time element included in the productive work time.	3
Chipping for all systems	Chipping (CHIP)	Starts when the grab moves out to the tree and ends when the grab moves out again for the next tree.	1
	Moving ($MOVE_{chipping}$)	Starts when the machine starts to move and ends when the machine stops moving.	2
	Miscellaneous ($MISC_{chipping}$)	Any other time element included in the productive work time.	3

CHIP was analysed based on 1701 single tree observations. CHIP was normalised to average tree size. Analysis of $MOVE_{chipping}$ per ha was done on the basis of 67 observations each representing moving along a striproad (FEBU, HARV and HARV-INT) or in a plot(MOMA). Standardisation to fixed conditions (N_2=450) was done using N_2 as covariate factor. $MOVE_{chipping}$ per tree was calculated as $MOVE_{chipping}$ per ha divided by 450. $MISC_{chipping}$ was analysed the same way as $MOVE_{chipping}$, but without covariate.

After felling and chipping (and extraction in integrated harvesting) the number of injuried trees was registered in all 48 plots. All visible damages exposing the xylem were registered irrespective of their size, according to Fröding (1983). Damaged trees were classified in two groups. (1) Visible root damages and damages lower than one meter above the ground, and (2) damages one to five meters above the ground.

All analyses have been carried out in SAS statistical package version 6.12 (Anon. 1989a, 1989b). Transformations have been made where appropriate in order to obtain normal distribution, following which the models were tested for outliers, influential observations, and constant variance. All means are calculated on untransformed data and Duncan's multiple-range test has been used for comparisons of means.

In the economical analyses Work place time was used as time basis. For all mechanised operations work place time was calculated as 1.49 multiplied with productive work time and for motormanual felling as 1,52 multiplied with productive work time (Samset 1995). Productive work time is considered equal to E_0 (Effective work-time according to Anon. 1978). Prices for chips and butt logs at roadside were assumed to 8 Euro per m^3_{loose}[1] and 38 Euro per m^3_{solid} respectively. The costs were set to 20 Euro per hour for motormanual felling, and 100 and 119 Euro per hour for the feller-buncher and the harvester respectively. The cost for the chip-harvester included the chip forwarder was set to 163 Euro per hour (Andersen pers. comm. 1999).

RESULTS

The felling productivity was about the same for HARV and FEBU. In HARV-INT the productivity was 20% lower, because the felling operation included the production of butt logs. MOMA halved the productivity compared with mechanised felling. The chipping productivity was 40% higher after FEBU compared with HARV, while MOMA was in-between. Measured in m^3_{loose} h^{-1} the chipping productivity is slightly lower in HARV-INT than in HARV (Tab. 4, Fig. 5).

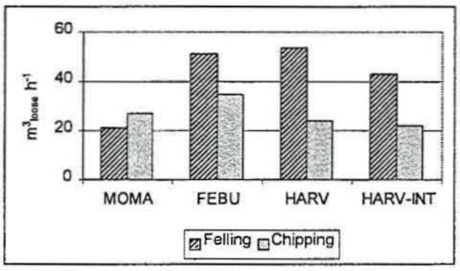


Figure 5. *Productivity for felling and chipping in m^3_{loose} per WP-hour.*

[1] In Denmark fuel chips are sold carriage paid (price round 11 Euro m^{-3}_{loose}), and the supplier is committed to establish inventory to guarantee year-round delivery. Road transport and storage costs are estimated to 3 Euro m^{-3}_{loose} (Bøllehuus et al. 1994, Suadicani 1996b).

Table 4. *Standardised time consumption for felling and chipping (centimin. tree^{-1}).*

		System			
Operation	Work element	MOMA	FEBU	HARV	HARV-INT
Felling	FELL	36 c*	24 a	23 a	29 b
	$MOVE_{felling}$	18 b	7 a	8 a	8 a
	$MISC_{felling}$	3	0	1	2
	$PW_{felling}$	57 c	31 a	32 a	39 b
Chipping	CHIP	37 b	34 b	48 c	27 a
	$MOVE_{chipping}$	3 b	1 a	5 c	3 b
	$MISC_{chipping}$	19 b	11 a	22 b	20 b
	$PW_{chipping}$	59 c	46 a	76 d	50 b

*In each row different letters indicate significant difference at $p<0.05$ level.
Standardisation functions:
FELL: MOMA: $-18+3.5\times D_{g2}$, FEBU: $8+1.1\times D_{g2}$, HARV: $20+0.2\times D_{g2}$, HARV-INT: $2+1.6\times D_{g2}$.
$MOVE_{felling}$: FEBU: $(1661+4\times N_2)\times 450^{-1}$, HARV: $(1971+4\times N_2)\times 450^{-1}$, HARV-INT: $(1914+4\times N_2)\times 450^{-1}$.
$CHIP_{standard}$: MOMA, FEBU, HARV: $CHIP\times 0.42/C_{g2}$, HARV-INT: $CHIP\times 0.29/C_{g2}$.
$MOVE_{chipping}$: MOMA: $(2838+9\times N_2)\times 450^{-1}$, FEBU: $(1321+9\times N_2=)\times 450^{-1}$, HARV: $(4963+9\times N_2=)\times 450^{-1}$, HARV-INT: $(5063+9\times N_2=)\times 450^{-1}$.

In whole tree chipping (MOMA, FEBU and HARV) the chipping costs made up 70-90% of the costs at roadside, while they made up 60% in HARV-INT. The income was somewhat higher in HARV-INT compared with whole-tree chipping because prices per m^3_{solid} at roadside is higher for saw logs than for fuel chips. The highest net income was obtained for FEBU and MOMA, and the main reason were the lower costs at roadside (Tab. 5).

Table 5. *Income and costs at roadside (Euro/ha).*

		MOMA	FEBU	HARV	HARV-INT
Income	Chips	1512	1512	1512	1044
	Short wood				752
	Total	1512	1512	1512	1796
Costs	Felling	134	365	414	515
	Chipping	1121	882	1294	952
	Forwarding				198
	Total	1255	1247	1708	1664
Net income		257	265	-196	132

It was not possible to apportion stand damage to either FEBU or MOMA because damages were only identified to plots. There was no significant difference in the overall damage rate comparing results between FEBU/MOMA, HARV and HARV-INT (Tab. 6). However, the damages were mostly located on the roots and on the lower part of the stem when using FEBU/MOMA and mostly located on the stem when using the HARV and HARV-INT. No significant difference was found in chip quality. The moisture content was 31-38%, and all samples fulfilled the Danish standard for fuel chips (Brüel & Sørensen 1987)(Tab. 7).

Table 6. *Damage rates on shelter trees caused by felling and chipping (%).*

System	MOMA and FEBU	HARV	HARV-INT
Injuries below 1 m	4.1 a*	3.3 a	4.6 a
Injuries 1-5 m	0.3 a	2.6 b	3.0 b
Total injuries	4.4 a	5.8 a	7.6 a

*In each row different letters indicate significant difference at $p<0.05$ level.

Table 7. *Chip quality parameters. No significant differences were found.*

SYSTEM	MOMA	FEBU	HARV	HARV-INT
Moisture content (%)	38	35	34	31
Content of accept chips (%)	79	75	78	80
Content of fines (%)	19	23	19	17

DISCUSSION

The productivity in motormanual felling and felling with feller-buncher are in line with former studies of harvesting smaller trees (Kofman 1983a,b, 1993). Chipping productivity is also in line with former studies. Motormanual felling or felling with feller-buncher followed by whole tree chipping proved to be superior to the two systems based on felling in herringbone pattern. However, motormanual felling or felling with feller-buncher had some drawbacks that should be included in the overall judgement. The feller-buncher was too small to handle large trees in an upright position if they were more than 4 m away from the base machine, and therefore the study only included felling of the second tree row counted from the striproad. A larger feller-buncher capable to handle trees in the fourth row could have been used instead. It is probable, that the felling productivity then would have been lower because of higher time consumption for handling trees far away even with a bigger and stronger machine. It is also probable that more damages would have been found if the system had included the fourth tree row. Motor-manual felling has the drawback that the trees lie where they fall. The chipper must drive in the stand when chipping, and it is therefore restricted to thinning in rows. Work place time for motormanuel felling may be underestimated by adding only 52 percent to the productive work time. Kofman (1983a) adds 70% to the productive work time for this kind of work. In HARV and HARV-INT chipping productivity was low, because of difficulties in feeding trees placed with an angle more than 30° from the striproad. A chipper less dependant on feeding angle would have improved the systems. More modern chip harvesters can feed trees with a wider angle because of wider funnel, and because the chippers are built up on articulated base machines. A 20% increase in the price of the butt logs would make HARV-INT competitive with MOMA and FEBU.

In the economic calculations it is assumed that the chipper determines system productivity. If terrain transport is extensive the chipper must wait for unloading, and the system does not gain from increased chipping productivity. Within the range of the study the chipper was able to work almost continuously because terrain transport was faster than the chipping process. For very long transportation distances a possibility is to use two tractors with chip containers, but the system becomes even more sensitive to disturbances. The same problem would arise if a more productive chip-harvester was used without increasing the load. It is essential that chipping and terrain-transportation are well synchronised.

Instead of using a harvester and a forwarder, HARV-INT could be done with a combined harvester/forwarder. This type of machine is designed to handle trees in upright position and to place the butt logs directly on the load. Terrain transport is done immediately and the tops can be placed properly for chipping.

CONCLUSIONS

Easy feeding is essential for chipping productivity, and the trees must be placed properly for chipping. Felling and bunching at the striproad with a feller-buncher gives the highest chipping productivity. Felling with a harvester does not give a satisfactory felling result. Integrated harvesting might be carried out with a combined harvester/forwarder instead of using a harvester and a forwarder.

The serial coupling between chipping and terrain transportation means that the slowest machine determines the productivity.

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PAPER III

Site Preparation and Planting in a Shelterwood of Norway Spruce – Technical Feasibility and Seedling Mortality

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Manuscript

Site Preparation and Planting in a Shelterwood of Norway Spruce – Technical Feasibility and Seedling Mortality

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ABSTRACT

The heath plantations in western Denmark mostly consists of Norway spruce stands that have shown to have little ecological stability. An objective is now to transform these, mostly single species even-aged plantations into mixed stands of partly native species. The aim of the present study was to quantify the productivity, quality, and damages rate of six site preparation methods in a shelterwood established either by row or selective thinning, the planting productivity following these methods were studied and the mortality of the planted seedlings (four species). A shelterwood was established in a 50-year-old Norway spruce stand consisting of approximately 550 trees per ha either by row or selective thinning. Site preparation was carried out using six different implements (including manual removal of humus when planting as reference). Seedling mortality varied considerably between the different tree species. Beech was very sensitive, while oak had a very low mortality. All mechanical site preparation resulted in lower mortality compared to manual removal of humus. The high mortality after manual removal of humus seems to be caused by a poor planting. The boom-mounted soil auger gives in many ways the best site preparation for planting, but the costs exceed the costs of tractor-drawn implements, especially when compared with tractor-drawn implements working in row thinning. Inverting site preparation (digging up a full bucket and inverting the profile with an excavator) seemed to destabilise the shelterwood.

Keywords: damages, forest operations, heath plantations, regeneration, soil scarification, survival, time consumption, work intensity, work quality, work study.

INTRODUCTION

Around the year 1800, hardly any forests were present in the western part of Denmark and approximately half of the land area was covered by heathland. The forests covered only about three percent of the total land area and were found exclusively in the eastern parts of Denmark. During the past 200 years, most of the heathland has been converted to other land uses – mainly farming and forestry (Sabroe 1966). At present, the Danish forest area is approximately 10% of the total land area.

The majority of the plantations on former heathland were established with mountain pine (*Pinus mugo* Turra) as the pioneer tree species and has been planted either directly in the heather or after site preparation. At the time of the regeneration of the first rotation of mountain pine, Norway spruce (*Picea abies* (L.) Karst.) became the most commonly used tree species. Approximately 80 % of the large conifer plantations that dominate the forests of the western part of Denmark are made up of Norway spruce (Tøttrup 1997).

Norway spruce has several advantages in plantations on poor soil, such as easy regeneration, rapid juvenile growth and a good timber quality (Schmidt-Vogt 1987). However, several disadvantages have become apparent. The large even-aged Norway spruce plantations are susceptible to windthrow, and in the twentieth century substantial areas were lost to windstorms. Root rot caused by the fungus *Heterobasidion annosum* (Fr.) Bref. is another serious threat to Norway spruce, especially in second and later rotations. It is not unusual that more than half of the trees in a Norway spruce plantation is infected with this fungus. As a result of these disadvantages, objectives have been set to transform these plantations into mixed forests composed mainly of native broad leaved species (Anon 1994, Clausen 1995). A method has been developed where the spruce plantations at a rather young stage (height < 15 m) are used as shelterwood stands under which several species are planted with or without site preparation (Løfting 1949, Oksbjerg 1951, Henriksen 1971, Neckelmann, 1995). Advantages with this method are a low risk for frost together with a shelter not so sensitive to windthrows. The planted species include silver fir (*Abies alba* Mill.), noble fir (*Abies procera* Rehd.), Douglas fir (*Pseudotsuga menziesii* (Mirb. Franco), grand fir (*Abies grandis* (Dougl.) Lindley), larch spp. (e.g., *Larix x eurolepis* Henry), beech (*Fagus sylvatica* L.), oak (*Quercus robur* L.), ash (*Fraxinus excelsior* L.) and sycamore (*Acer pseudoplatanus* L.).

Site preparation before planting is common on clearcuts especially on soils characterised by a thick raw humus layer. Site preparation results in several advantages such as easy planting, removal of competing weed and reduced attacks from weevils (Neckelmann 1976, 1995, Örlander & Gemmel 1989, Berg 1991). Site preparation might follow the establishment of a shelterwood. The goal should be to combine the advantages of the two operations, but there are also disadvantages such as operational difficulties, injuries on the shelter trees and increased risk of windthrows (Fjeld 1996, Hagner 1990, Westerberg & Hofsten 1996).

The aim is to study the productivity, quality, and damages rate of six site preparation methods in a shelterwood established either by row or selective thinning, the planting productivity following these methods, and the mortality of the planted seedlings (four species).

MATERIALS AND METHODS

The study area was a 50 year old Norway spruce stand (8.6 ha) located in north-western Denmark (56°30'N, 8° 22'E). The soil was poor and sandy and covered by an approximately 10 cm thick layer of raw humus, and no hard pan was found in the soil. Terrain conditions were class 1 for bearing capacity, surface evenness and ground slope in which class 1 represents very easy conditions and 5 very difficult conditions (Anon. 1991). The stand was originally planted in rows with approximately 1.4 m between and within the rows. A striproad system was established in former thinnings dividing the stand into 108 plots (57×15 m) surrounded by striproads.

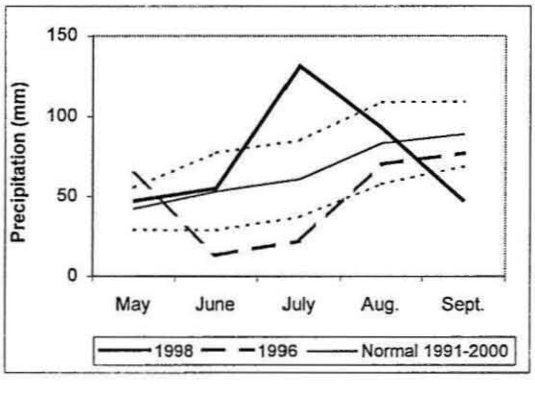


Figure 1. Precipitation in May to September 1998 compared with average precipitation 1991-2000 (95% confidence intervals are dotted). A typical dry growth season (1996) is also shown.

The shelterwood was established in May 1997, the site preparation in late October 1997, and the planting in March 1998. The local precipitation in the growth season of 1998 is shown in fig. 1. The summer was cold with few sun-hours, many wet days, and few warm summer-days. The precipitation in 1998 was the second highest recorded in Denmark (Anon. 1999). The distribution of plots to blocks, shelterwood types, site preparation methods and workers is shown in fig 2.

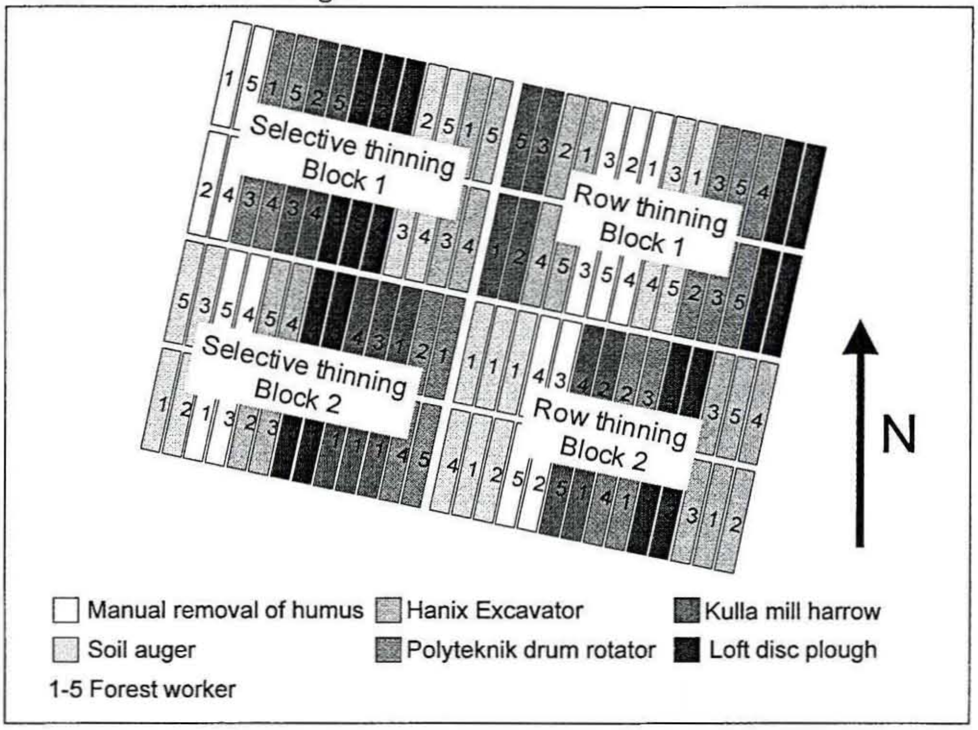


Figure 2. *The study area.*

The stand was divided into two blocks. In each block row thinning and selective thinning had been performed to establish the shelterwood. Row thinning was established by the removal of every second row (normally row no. 2, 4, 6 and 8 out of 9 tree rows) to give the best possible accessibility for site preparation implements. Selective thinning was established by leaving the most vigorous trees equally distributed without taking site-preparation implement accessibility into consideration. Block 1 was established by conventional shortwood harvesting, and block 2 was established by harvesting of fuel chips (stand data in Table 1).

Table 1. Stand data for the two blocks and row and selective thinning.

	Selective thinning	Row thinning
Block 1		
Area (ha)	2.0	2.1
D_{g3} (cm)	18.3	18.0
N_3 (trees ha^{-1})	536	569
G_3 (m^2 ha^{-1})	14.1	14.5
V_3 (m^3 ha^{-1})	106	110
Block 2		
Area (ha)	2.1	2.4
D_{g3} (cm)	18.0	17.1
N_3 (trees ha^{-1})	524	569
G_3 (m^2 ha^{-1})	13.4	13.1
V_3 (m^3 ha^{-1})	101	97

Six site preparation methods were studied (Table 2):

(1) Manual site preparation (MANUAL). The humus layer was removed manually with the forest spade (type: Fiskars/Lysbro no. 176) in spots of 30×30 cm at planting.

(2) The Loft disc plough (PLOUGH) produced a 40-60 cm wide strip.

(3) The Kulla mill harrow (HARROW) has three tines that remowed the raw humus layer and harrowed the upper part of the mineral soil (0-5 cm). The patches were approximately 60 cm wide and 100 cm in length.

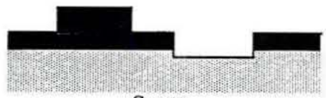
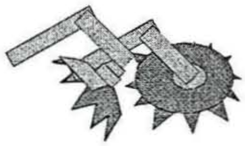
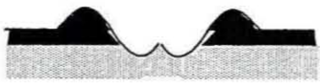
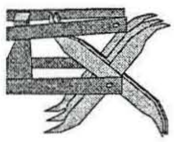
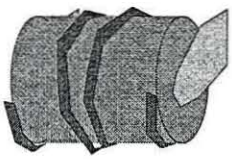
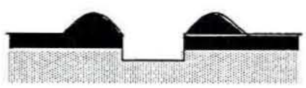
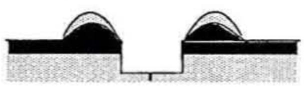
(4) The Polyteknik drum rotator (ROTATOR) has a hydraulically driven drum with two oblique ribs. The ribs pushed aside the humus layer, while the drum intermittently rotated backwards. The patches were approximately 60 cm wide and 100 cm in length.

(5) The soil auger (AUGER) was mounted on a harvester (Thomsen 1998). It made circular spots with a diameter of 40 cm, where the soil was loosened to a 60-cm depth. The oblique rib on the top-plate removed the humus layer.

(6) The Hanix n450 excavator (EXCAVATOR) was small, belt driven, and equipped with a 100-litre bucket (50 cm wide). Scarification involved digging up a full bucket and inverting the profile. This scarification method is known as inverting site preparation (Örlander et al. 1998). The patches were approximately 50 cm wide and 100 cm in length. The depth of the treatment was estimated at 50 cm at the deepest point.

Implement 2-4 was tractor-drawn and implement 5-6 was boom-mounted.

Table 2: Description of site preparation implements.

BASE MACHINE	IMPLEMENT	PRINCIPAL RESULT
MANUAL (Forest worker)		 Spots
PLOUGH Valmet 6400 farm tractor 70 kW Disc plough, tractor drawn. Weight: 5.0 t Width: 2.32 m Length: 7.3 m		 Strips
HARROW Fendt 308 farm tractor 57 kW Mill harrow, tractor drawn. Weight: 4.4 t Width: 2.19 m Length: 5.8 m		 Patches
ROTATOR Systra 750 h farm tractor 53 kW Drum rotator, tractor drawn. Weight: 4.1 t Width: 1.95 m Length: 5.4 m		 Patches
AUGER Silvatec 854F forwarder 114 kW Soil auger, Boom mounted. Weight: 9.5 t Width: 2.37 m Length: 7.4 m		 Spots
EXCAVATOR Hanix n450 33 kW Excavator, Boom mounted. Weight: 4.6 t Width: 1.85 m Length: 4.0 m		 Patches

Site preparation was done in the space between the tree rows. The instruction was to establish 2500-3000 suitable planting spots per ha in the space between the tree rows. All operators were experienced in operating their own site preparation implement, except the operator on the ROTATOR. He was experienced in operating other equipment, but had only been operating the ROTATOR for one week.

Planting of the bare-rooted seedlings was carried out manually with a forest spade (type: Fiskars/Lysbro no. 176). The seedlings were wedge-planted (the spade split the soil, the plant is put down in the wedge and the soil is trodden down) and the workers were instructed to plant 2500–3000 seedlings per ha. uniformly spaced. Planting should be done in exposed mineral soil if possible. In plots where mechanical site preparation had taken place some areas were left unprepared because of inaccessibility, and in such areas seedlings were to be planted in unprepared soil. A species composition of 50% beech (provenance Frederiksborg 2/0+ 30-50 cm), 30% silver fir (75% Gariglione 2/1s 10-20 cm, 25% Schwarzwald 2/2 15-30 cm), 15% oak (Agder B5448 2/0+) and 5% Douglas fir (Sorø 2/1 20-40 cm) was aimed at.

Productive work time (Björheden 1995) for site preparation and planting was recorded in continuous time studies using SIWORK3 software and a Husky Hunter computer (Rolev 1988). Time consumption for site preparation was divided into scarification time (SCAR), positioning time (POS) and turning time (TURN). Time consumption for planting was divided into planting time (PLANT) and preparation time to fetch plants etc. (PREP)(Table 3).

The costs of site preparation and planting was estimated as prevailing market prices per work place hour supplied by the local forest district. Costs per work place hour for PLOUGH, HARROW and EXCAVATOR was set to 50 Euro h^{-1}, ROTATOR to 56 Euro h^{-1}, AUGER to 75 EURO h^{-1}, and worker to 20 Euro h^{-1} (Paul Schmidt Andersen pers. comm. 1999). A low price per hour was set for the AUGER because an unoccupied harvester was used. Work place time for site preparation was calculated as the productive work time multiplied with 1.46, and work place time for planting was calculated as the productive work time multiplied with 1.52 (Samset 1995).

The treatment intensity of the site preparation was studied directly as the number of patches or spots and as the number of site preparation lines. Patches or spots were registered during the time study, and mineral soil should be exposed to qualify as a patch or spot (all implements except PLOUGH). The number of site preparation lines was registered for the three drawn implements (PLOUGH, HARROW and ROTATOR). Although the HARROW and the ROTATOR produced patches, it was easy to identify the site preparation lines. In each plot the number of site preparation lines was registered along three lines perpendicular to the direction of site preparation. The proportion of the soil surface that had been treated by the site preparation implement was then calculated as the area of strips/patches/spots per ha.

Table 3: Work elements.

Operation	Work elements and abbreviations	Description and demarcations	Priority
Site preparation with tractor-drawn implements	Scarification (SCAR)	Starts when the implement is lowered for scarifying and ends when it is lifted for POS or TURN.	1
	Positioning (POS)	Starts when the implement is lifted and ends when the implement touches the ground for SCAR.	2
	Turning (TURN)	Starts when the implement is lifted and the equipment drives out of the plot to turn. Ends when the equipment has turned and the implement is lowered for SCAR.	3
Site preparation with boom-mounted implements	Scarification (SCAR)	Starts when the implement touches the ground and ends when the implement is lifted from the ground (AUGER) or ends when the bucket is lifted after the patch has been smoothed out (EXCAVATOR).	1
	Positioning (POS)	Starts when the implement is lifted from the ground (AUGER) or starts when the bucket is lifted after the patch has been smoothed out (EXCAVATOR). Ends when the implement touches the ground. *Positioning therefore includes both boom operations and driving.*	2
	Turning (TURN)	Starts when the base machine starts to drive and the base machine drives out of the plot to turn. Ends when the base machine has turned, driven into the stand again and stopped.	3
Planting of seedlings	Planting (PLANT)	Starts when the spade is trodden into the soil for planting, and ends when the spade is trodden into the soil again for planting the next plant or when the worker walks away for fetching plants.	1
	Preparation (PREP)	Start when the worker leaves to fetch more plants and ends when the spade is trodden into the soil for planting.	2

In addition, the number of planted seedlings per ha and the number of seedlings per ha planted in unprepared soil was registered because differences in treatment intensity was expected to reflect on those.

Mortality on seedlings, damages on shelter trees and the number of windblown trees was registered as indicators of the quality of the site preparation. Two year after planting all seedlings was registered as dead or alive. All visible injuries on the above ground part of the shelter trees were registered after site preparation irrespective of their size. Cambium should be exposed to qualify as an injury (Fröding 1983). Injuries on roots were not registered, but as an indication of root damages, the number of windblown trees were registered three years after the site preparation. After planting the workers were asked to give their preference according to the site preparation methods.

The experimental design was a split-plot model including two blocks, where row thinning or selective thinning was whole-plot factor and the six site preparation methods were split-plot factors. All analyses were carried out in SAS statistical package version 6.12 (Anon 1989a, 1989b). Models were tested for outliers, influential values and constant variance in the guided data-analysis module. Transformations have been made where appropriate in order to obtain normal distribution, but all means are calculated on untransformed data. Bonferroni's t-test of differences between means was used to test differences between site preparation methods and row or selective thinning for each site preparation method.

The same statistical model (1) was used to test differences in site preparation productivity, treatment intensity and damages on shelter trees.

$$X_{ijk}=\mu+\alpha_i+\beta_j+(\alpha\beta)_{ij}+\nu_k+\eta_{ik}+\varepsilon_{ijk} \quad (1)$$

where:
X_{ijk} = The observation (time study results or other registrations)
μ = grand mean
α_i = the effect of row or selective thinning (whole-plot factor)
β_j = the effect of the site preparation method (split-plot factor)
$(\alpha\beta)_{ij}$ = interaction between row or selective thinning and site preparation method
ν_k = the effect of block
η_{ik} = interaction between row or selective thinning and block
ε_{ijk} = experimental error

Differences in planting productivity and mortality were tested in a somewhat more complex model including the effect of the different workers (2).

$$X_{ijkl}=\mu+\alpha_i+\beta_j+\varphi_k+(\alpha\beta)_{ij}+(\alpha\varphi)_{ik}+(\beta\varphi)_{jk}+(\alpha\beta\varphi)_{ijk}+\nu_l+\eta_{il}+\lambda_{ijl}+\kappa_{ikl}+\varepsilon_{ijkl} \quad (2)$$

where:
X_{ijkl} = The observation (time study results or other registrations)
μ = grand mean
α_i = the effect of row or selective thinning (whole-plot factor)
β_j = the effect of the site preparation method (split-plot factor)
φ_k = the effect of the worker
$(\alpha\beta)_{ij}$, $(\alpha\varphi)_{ik}$, $(\beta\varphi)_{jk}$ and $(\alpha\beta\varphi)_{ijk}$ = interactions between the above factors
ν_l, η_{il}, λ_{ijl} and κ_{ikl} = block effects
ε_{ijkl} = experimental error

In the analyses, the mortality in percent is weighted by the number of seedlings.

RESULTS

In overall SCAR accounted for 50-80 % of the time consumption for site preparation, POS 10-30% and TURN 5-20% (Table 4).

SCAR was significantly different between all five implements. For the tractor-drawn implements SCAR was proportional to the total length of the strips, because the working speed for each implement was approximately constant. The average speed was a little lower in selective thinning than in row thinning except for the ROTATOR. SCAR was not significantly different between row and selective thinning because the lower speed in selective thinning was compensated by the lower treatment intensity. For the AUGER and the EXCAVATOR, SCAR was proportional to the number of patches/spots. The AUGER had a slightly lower productivity in selective thinning.

POS was greater for boom-mounted implements than for tractor-drawn implements. For the tractor-drawn implements POS was significantly higher in selective thinning than in row thinning. In row thinning, no differences in POS between the three tractor-drawn implements were found, but the HARROW had lower POS in selective thinning than PLOUGH and ROTATOR. For the AUGER and the EXCAVATOR POS was not influenced by row or selective thinning.

TURN was lower for the boom-mounted implements than for the tractor-drawn implements because the boom-mounted implements reached a wider area at a time.

The PLOUGH and the HARROW were the two most productive implements. They were both more productive in row thinning than in selective thinning. The ROTATOR was slower than the two other tractor-drawn implements, but faster than the boom-mounted implements. The ROTATOR was also more productive in row thinning than in selective thinning. The AUGER was more productive than the EXCAVATOR, and the two boom-mounted implement's productivity was not influenced by row or selective thinning.

Time consumption for planting (PLANT) was more than twice as high in MANUAL than in the mechanically prepared plots, because MANUAL included site preparation in the planting operation (Table 4). There was no significant difference in PLANT between the five mechanical site preparation methods. It did appear though, that it was somewhat quicker to plant in plots prepared by the AUGER. The row or selective thinning did not influence planting productivity, but the planting speed varied considerably between the five workers. The fastest had an average productivity of 161 seedlings per hour (work place time) and the slowest 115 seedlings per hour.

Table 4. Time consumption for site preparation and planting. Percent of productive work time (PW) within brackets.

		MANUAL		PLOUGH		HARROW		ROTATOR		AUGER		EXCAVATOR	
Operation	Work element	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning
Site preparation	SCAR			2.1 a*	2.1 a	2.8 b	2.8 b	4.4 c	3.8 c	5.3 d	5.2 d	7.2 e	7.6 e
(hour ha^{-1})				(69)	(42)	(80)	(62)	(74)	(53)	(56)	(60)	(58%)	(60)
	POS			0.3 a	2.2 c	0.1 a	0.9 b	0.3 a	1.7 c	3.7 d	3.1 d	4.7 d	4.3 d
				(9)	(45)	(3)	(21)	(5)	(24)	(39)	(37)	(38%)	(34)
	TURN			0.7 ab	0.7 ab	0.6 ab	0.8 b	1.3 c	1.6 c	0.4 ab	0.3 a	0.6 ab	0.7 b
				(23)	(13)	(17)	(18)	(22)	(22)	(5)	(3)	(5)	(6)
	PW_{scar}			3.1 a	5.0 b	3.6 a	4.5 b	6.0 c	7.1 d	9.4 e	8.6 e	12.5 f	12.6 f
				(100)	(100	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Planting of	PLANT	0.45 a	0.49 a	0.20 b	0.21 b	0.22 b	0.22 b	0.20 b	0.20 b	0.19 b	0.19 b	0.21 b	0.21 b
seedlings		(90)	(91)	(80)	(79)	(81)	(80)	(80)	(79)	(79)	(79)	(79)	(81)
(min $seedling^{-1}$)	PREP	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		(10)	(9)	(20)	(21)	(19)	(20)	(20)	(21)	(21)	(21)	(21)	(19)
	PW_{plant}	0.50 a	0.54 a	0.25 b	0.27 b	0.27 b	0.28 b	0.25 b	0.26 b	0.24 b	0.24 b	0.27 b	0.26 b
		(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)

*In each row different letters indicate significant difference at $p<0.05$ level.

Table 5. Productivity and costs for site preparation and planting.

	MANUAL	PLOUGH		HARROW		ROTATOR		AUGER	EXCAVATOR
	Row/selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row/selective thinning	Row/selective thinning
Productivity									
Site preparation (hour ha^{-1})		4.5	7.3	5.3	6.6	8.8	10.4	13.1	18.3
Planting(seedlings $hour^{-1}$)	76	158	146	146	141	158	152	164	149
Costs									
Site preparation (Euro ha^{-1})		227	357	263	333	509	560	986	916
Planting (Euro ha^{-1})*	789	380	411	411	426	380	395	366	403
TOTAL (Euro ha^{-1})	789	607	768	674	758	889	955	1352	1319

*Based on 3000 seedlings per ha.

The economic analysis showed that the lower planting costs more than compensated the site preparation costs for the PLOUGH and for the HARROW and, conversely, site preparation with AUGER and EXCAVATOR was so expensive that the lower planting costs could not justify site preparation costs (Table 5).

The EXCAVATOR prepared fewer patches than the other two patch scarifiers (HARROW and ROTATOR) (Table 6). The HARROW and the ROTATOR made fewer patches in selective thinning than in row thinning. The AUGER also made fewer spots in selective thinning than in row thinning. No difference in the number of prepared strips was found between the three tractor-drawn implements or between row thinning and selective thinning. Anyhow there is an indication of fewer prepared lines in selective thinning than in row thinning for all three implements. It also seems that the ROTATOR made fewer strips in selective thinning than the other two implements.

The highest number of seedlings per ha was found in plots where the PLOUGH did the site preparation and the fewest seedlings in plots where the EXCAVATOR did the site preparation. There were fewer seedlings per ha in selective thinning than in row thinning for all implements except for the EXCAVATOR, but the difference in number of seedlings per ha between row thinning and selective thinning is not significant for any site preparation method. The mean number of plants planted by the five planters ranged from 2724 to 2990 seedlings per ha.

Practically no seedlings were planted in unprepared soil in plots where the AUGER did the site preparation. More, but also relatively few seedlings were planted in unprepared soil where the EXCAVATOR did the site preparation. More seedlings were planted in unprepared soil in selective thinning than in row thinning, when looking at the three tractor-drawn implements, and finally most seedlings were planted in unprepared soil where the ROTATOR did the site preparation. Some workers showed up to be quite unwilling to plant in unprepared soil, while other workers followed the instruction more faithfully. The mean number of seedlings planted in unprepared soil ranged from 6 to 104 seedlings per ha between the five workers.

Plant mortality has been largest for beech seedlings, followed by Douglas fir, silver fir, and oak in that order (Table 7). For beech seedlings mortality is largest in MANUAL, and lowest where the AUGER and the EXCAVATOR had made a thorough site preparation. The other species showed a similar trend to beech, but mortality was too low to show significance. No significance was found when assessing mortality against row or selective thinning. Date of planting was tested, but it did not influence mortality. The individual worker influenced mortality although level of significance was

Table 6. The intensity of the site preparation.

	MANUAL		PLOUGH		HARROW		ROTATOR		AUGER		EXCAVATOR	
	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning
Patches or spots (No. ha^{-1})	-	-	-	-	2517 bc*	2054 de	2787 ab	2267 cd	3108 a	2746 b	1701 e	1811 e
Strips (No. 100 m^{-1})	-	-	55 a	49 a	53 a	49 a	52 a	46 a	-	-	-	-
Seedlings (No. ha^{-1})	3038 bc	2662 bcde	3593 a	3184 ab	2822 bcd	2636 cde	3173 ab	2861 bcd	3064 bc	2657 bcde	2240 e	2485 de
Seedlings in not scarified soil (No. ha^{-1})	(3038)	(2662)	43 bc	107 abc	19 bc	108 abc	130 ab	176 a	0 c	4 c	58 bc	15 bc
Proportion Prepared soil surface (%)	3	2	28	25	20	16	17	14	4	3	9	9

*In each row different letters indicate significant difference at $p<0.05$ level.

Table 7. The quality of the site preparation.

	MANUAL		PLOUGH		HARROW		ROTATOR		AUGER		EXCAVATOR	
	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning	Row thinning	Selective thinning
Mortality beech (%)	23 ab*	29a	20 bcd	14 cde	21 bc	17 bcde	15 bcde	16 bcde	12 de	11e	10 e	12 e
Mortality Douglas fir (%)	7.4 ab	11.3 a	6.4 ab	2.2 ab	6.4 ab	0.0 b	5.1 ab	1.0 b	0.8 b	3.1 ab	4.1 ab	1.5 b
Mortality silver fir (%)	3.9 ab	5.3 a	2.8 ab	1.5b	4.0 ab	1.9 b	3.1 ab	3.1 ab	2.2 ab	1.7 b	1.5 b	1.9 b
Mortality Oak (%)	0 a	1.4 a	0.4 a	0.4 a	1.2 a	0.8 a	1.2 a	0.4 a	0.3 a	0 a	0 a	0.4 a
Damage rate on shelter trees (%)	0	0	4 a	3 a	7 ab	13 b	2 a	3 a	1 a	2 a	5 a	3 a

*In each row different letters indicate significant difference at $p<0.05$ level.

not strictly reached. In beech the mean mortality for the five workers varied between 14.2 and 20.1%.

The HARROW made by far the most injuries on the shelter trees (Table 7). The AUGER, where the base machine sticks to the strip roads, accounts for less damage than the other mechanical site preparation methods, which all drive in the stand.

Three years after thinning and site preparation only 45 of the 4758 shelter trees were wind thrown. Forty percent (18 trees) toppled in plots prepared with the EXCAVATOR and only 7% (3 trees) toppled in plots with MANUAL, of which two trees were placed in the western margin of the stand. 11% (5 trees) toppled in plots prepared with the AUGER of which two were placed in the western margin of the stand. 13-16% (6-7 trees) toppled in plots where one of the tractor-drawn implements did the site preparation.

The five workers agreed that is was most convenient to plant where the AUGER and the PLOUGH made the site preparation. They also agreed that planting in plots without site preparation was cumbersome, and planting in plots prepared by the excavator was unpleasant because of resistance offered by branches, roots, humus etc. that had been inverted into the planting hole.

DISCUSSION

The technical feasibility of site preparation in shelterwoods has been investigated by Fjeld (1994, 1996). He points out, that stand density affects the intensity in site preparation and that boom-mounted implements are less affected by stand density than tractor-drawn implements. Westerberg & von Hofsten (1996) compared the work quality of a tractor-drawn and a boom-mounted site preparation implement and found a higher treatment intensity and a lower damage rate where site preparation was done with the boom-mounted implement. Both studies focused on natural regeneration and the shelterwoods consisted of fewer and larger trees randomly distributed unlike the present study that consisted of more, smaller trees standing in rows. This study shows that it is technically feasible to do site preparation with all the tested implements in shelterwoods having 500-600 stems per ha in both row and selective thinning.

One reason for site preparation is to ensure faster planting. The planting speed is indeed affected by the site preparation method and increased planting efficiency alone can often justify site preparation.

The tractor-drawn implements reposition if a tree obstructs their path. The implement must be lifted, while the machine changes track, because the tractor is difficult to manoeuvre while scarifying. If each second tree row was removed, no trees obstructed the path, and POS would be zero. Therefore row thinning minimises POS for the tractor-drawn implements. In selective thinning POS is lower for the HARROW than for the PLOUGH and ROTATOR because it is loosely suspended behind the tractor. It gives the HARROW better manoeuvrability without lifting the implement. POS for the boom-mounted implements occurs each time the implement moves from one patch or spot to the next and therefore POS is larger for the boom-mounted implements than for the tractor-drawn implements. The productivity could be increased if the tractor was equipped with two implements like the "Inversal", "TTS10", or "Skogstjärnan".

The productivity for the boom-mounted implements is almost proportional to the number of patches or spots, while the time consumption of tractor-drawn implements is mostly determined by the length of the strips. Therefore competitivity of the boom-mounted implements would show comparative improvement with decreasing treatment intensity. Anyhow site preparation with the boom-mounted implements was so expensive compared with the tractor-drawn implements that extra costs must be expected irrespective of the site-preparation intensity. If the AUGER could prepare more than one spot at a time, its productivity would be boosted significantly.

The difference in the implements size was expected to result in higher treatment intensity with the ROTATOR than with the PLOUGH and the HARROW, but the opposite happened which is probably attributable to difficulties in manoeuvring the ROTATOR because the base machine was rear-heavy. This could also explain the ROTATOR's high TURN. Unexpectedly the ROTATOR had higher speed in selective thinning than in row thinning, but it might be a result of experience gained during the study. The slightly lower productivity of the AUGER in selective thinning might be a result of more difficult stand conditions in the four western plots (more narrow and slightly swaying striproads). The AUGER made more spots in row thinning than in selective thinning, even though the average number of trees per ha was lower in selective thinning than in row thinning. One possible explanation could be that the many trees in the row closest to the strip road forced the operator of the soil auger to place the holes closer to each other because the lateral movement of the boom was impeded. The low number of patches where the EXCAVATOR did the site preparation is probably caused by the boom's requirement for space. Each patch also seems quite large, and therefore their distribution soon becomes extensive.

The number of seedlings per ha and the number of seedlings planted in unprepared soil reflects the coverage of the site preparation, which means that the workers tend to plant more seedlings where site preparation is more complete. Only plots prepared by the EXCAVATOR do not reach the target of 2500 to 3000 seedlings per ha, and the workers reach the number of planted seedlings by planting more than one plant in each patch.

The HARROW caused many injuries to shelter trees owing to the loose suspension of the implement. When the tractor drives over a stump the

HARROW swings out laterally and often hits a tree. The loose suspension is therefore both advantageous in that it increases manoeuvrability and disadvantageous in causing damage to the shelter trees.

Although a hurricane hit Denmark in December 1999 only 100 km south of the study area, the stand was not affected by serious windthrows. Damages to the roots are unavoidable during site preparation and different types of site preparation damage the root system to differing extents. Root damages made by the EXCAVATOR seems to reduce the stability of the stand seriously if 50 cm thoroughly site preparation is made.

Some other studies have investigated the mortality of seedlings according to different site preparation methods under a shelterwood, and they show different results. Neckelmann (1976) found much lower mortality in silver fir after site preparation under shelterwood, while Gemmel et al. (1996) found no effect on mortality of beech and oak after site preparation under shelterwood. Löf (2000) found lower mortality, in beech and oak, but he concludes that acceptably low mortality can be achieved without site preparation. The mortality in the present study is mostly dependent on tree species, but site preparation is also significant. Mortality below 5% is normally judged as insignificant, and this means that only beech and Douglas fir had significant mortality. The high precipitation in 1998 has favoured the seedling growth and resulted in the generally low mortality. Under less favourable conditions (e.g. 1996 as shown in Fig. 1) a higher mortality would have been expected, especially in seedlings planted in MANUAL. It is unknown whether a larger difference between the different mechanical site preparation methods would have shown up.

The higher mortality in plots with MANUAL can probably be attributed to the fact that the soil could not be adequately compacted around the seedling, as this is done by foot, in the relatively small holes in the organic layer. All site preparation methods seem to create the prerequisites for improved quality of manual planting and thereby obtain lower mortality (Berg 1991, Neckelmann 1976, Örlander & Gemmel 1989). Lower mortality in augered or excavated plots relative to the mortality in plots treated by tractor-drawn implements can be ascribed to the deep subsoiling treatment, that blends the mineral soil and humus and severs the roots. This might improve humidity in the soil and reduce root-competition from the shelter trees. However, the most probable explanation of the lower mortality is that the method facilitated a better planting. This is supported by the workers' preferences. Workers prefer to do a proper job, and their preferences can therefore be considered as an indication of better planting quality.

CONCLUSION

The mortality is an important factor, because replanting is expensive and often inefficient. Therefore mortality must be given high weighting in the judgement of the site preparation methods. From this point of view the two intensive site preparation methods, the AUGER and the EXCAVATOR can be recommended, but in spite of the low mortality, the EXCAVATOR can not be recommended because of the destabilising effect upon the stand.

Planting in MANUAL has been used for many years and the method is attractive because the shelter is not destabilised by site preparation. In stands where stability concerns demand it, and if robust tree species are planted, this method can be recommended.

If accessibility in the stand is good the PLOUGH or the HARROW can be recommended. They are both cheap site preparation methods and the results seem satisfactory. The HARROW must be further stabilised to avoid damaging the shelter trees.

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Natural Regeneration in a Shelterwood of Norway Spruce on Former Heathland

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ABSTRACT

A substantial part of heathland in Denmark has been converted to other land uses, such as farming or forestry. For forestry purposes, non-native tree species such as Norway spruce and mountain pine have been used in the conversion process. An objective is now to transform these, mostly single species, even-aged plantations into mixed stands of predominantly native species. The aim of this study is to investigate the use of natural regeneration in the conversion of a Norway spruce stand into a mixed stand. A shelter was established in a 50 year-old Norway spruce stand consisting of approximately 550 stems/ha. In 1997 site preparation was carried out using six different implements. In 2000 the number of naturally regenerated seedlings was counted in site prepared and unprepared parts of the stand. The results show that natural regeneration under a shelter is possible even without site preparation (more than 60.000 seedlings per ha. after two years growth), but site preparation significantly improves regeneration (more than 200.000 seedlings per ha. after two years growth). A number of tree species can regenerate, but the existence of seed sources plays a vital role for the mixture of species in the regeneration. The study has also shown a positive influence of machines driving on the site making some slight humus and soil disturbance.

Keywords: Denmark, heathland, natural regeneration, Norway spruce, Picea abies, scarification, site preparation, shelterwood

INTRODUCTION

Around the year 1800, hardly any forests were present in the western part of Denmark and approximately half of the land area was covered by heath growing on a poor sandy soil. Forests covered only about three percent of the total land area and were found exclusively in the more fertile eastern parts of Denmark. During the past 200 years, most of the heath has been converted to other land uses – mainly farming and forestry (Sabroe 1966). At present, the Danish forest area is approximately 10% of the total land area.

The majority of the plantations on the former heathland was afforested using mountain pine (Pinus mugo Turra) planted directly or after soil scarification. At the time of regeneration after the first rotation, Norway spruce (Picea abies (L.) Karst.) became the most commonly used tree species, although Norway spruce is not a native tree species in Denmark. Approximately 80 % of the conifer plantations dominating the forests in the western part of Denmark consist of Norway spruce (Tøttrup 1997).

Norway spruce has several advantages in plantations on poor soil such as easy regeneration, rapid juvenile growth, and good timber quality (Schmidt-Vogt 1987). However, several disadvantages have become apparent. Even-aged Norway spruce plantations are susceptible to windthrow, and in the twentieth century substantial forest areas have been destroyed by storms. Root rot (caused by the fungus Heterobasidion annosum (Fr.) Bref.) has become increasingly common, and it is not unusual that more than half of the trees in a Norway spruce plantation is infected with this fungus. As a result of these disadvantages, objectives have been set to transform these plantations into mixed forests composed partly of native broad leaved species (Anon. 1994, Clausen 1995). A method has been developed where the spruce plantations at a rather young stage (height < 15 m) are used as shelterwood stands under which several species are planted with or without site preparation (Neckelmann, 1995). Advantages with this method are a low risk for frost together with a shelter not so sensitive to windthrows. The planted species include silver fir (Abies alba Mill.), noble fir (Abies procera Rehd.), Douglas fir (Pseudotsuga menziesii (Mirb. Franco), grand fir (Abies grandis (Dougl.) Lindley), larch spp. (e.g., Larix x eurolepis Henry), beech (Fagus sylvatica L.), oak (Quercus robur L.), ash (Fraxinus excelsior L.) and sycamore (Acer pseudoplatanus L.).

Natural regeneration of these spruce plantations has only been proposed in exceptional cases. This is partly because of bad experiences, but mostly because planting of Norway spruce has shown to be a reliable and cheap method (Magnussen 1985). In the other Scandinavian countries – where Norway spruce is a native tree species – natural regeneration is far more common (Skoklefald, 1989; Hånell, 1993; Holgen & Hånell, 2000). Natural regeneration may be used in Denmark on certain localities or supplemented by planting or sowing (Magnussen 1985). In this way, the cost of regeneration is likely to be lower than planting exclusively.

The aim of the study is to investigate the natural regeneration under a Norway spruce shelterwood in the conversion into a mixed stand of partly native species.

MATERIALS AND METHODS

The study area was a 8.6 ha stand in the northwestern part of Denmark (56° 30′ N, 8° 22′ E) (Fig. 1). The soil was poor and sandy and covered by an approximately 10 cm thick layer of raw humus, and no hard pan was found in the soil.

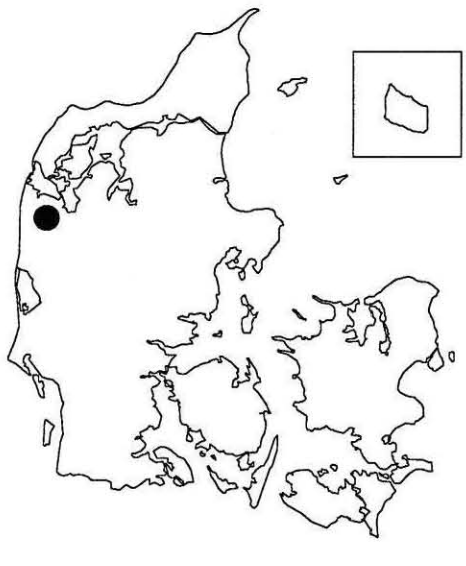

Figure 1. *The locality of the study.*

The stand was dominated by Norway spruce, planted in the period 1947-1950 under a shelter of mountain pine, which in turn was planted on open heathland 100 years ago. It was a typical stand for this kind of site. More than 93% of the trees were Norway spruce, but other species found in the stand included grand fir (4%), Scots pine (Pinus silvestris L.)(2%), Japanese larch (Larix leptolepis (Sieb. & Zucc.) Endl.)(<0.5%), and Douglas fir

(<0.2%). The shelterwood was established in 1997, consisting of approximately 550 shelter trees per ha. In spring 1998, site preparation was carried out, and 3000 plants per ha were subsequently planted – with a species composition of 50% beech, 30% silver fir, 15% oak and 5% Douglas fir. Natural seed fall took place in spring 1999. The shelterwood was weed-free when established owing to the density of the original stand.

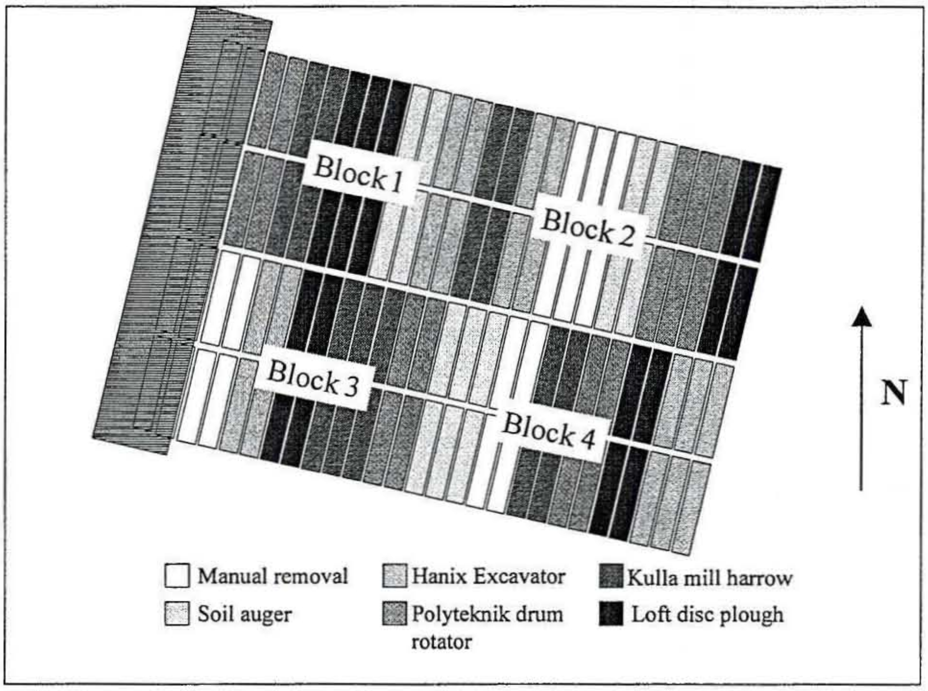

Figure 2. *Experimental layout.*

The experiment consists of four blocks, six site preparation treatments randomised in each block (24 plots, 0.3-0.45 ha each). The plots were divided in either 4 or 6 sub-plots according to size resulting in a total of 108 sub-plots. Regeneration was sparse in the western part of the stand because of draught and the two most western plots were therefore excluded from the study (Fig. 2).

The treatments were one manual and five mechanised site preparation methods. Manual removal of the humus layer in a 30 cm × 30 cm square with a forestry spade was done in spring 1998 just before planting Mechanised site preparation was carried out in autumn 1997.

The Loft disc plough produces a 40–60 cm wide strip. The depth depends on the disc angle, and the discs can roll over stumps and larger roots. The Kulla mill harrow has three tines that remove the humus layer and harrow the upper part of the mineral soil (0-5 cm). The patches are approximately 60 cm wide and 100 cm in length. The Polyteknik drum rotator has a hydraulically driven drum on which two oblique ribs are mounted. The ribs push aside the humus, when the drum intermittently rotates backwards. The patches are approximately 60 cm wide and 100 cm in length. The soil auger is boom mounted on a harvester (Thomsen 1998). The soil auger makes circular planting holes with a diameter of 40 cm and loosens the soil to a 60-cm depth. An oblique rib on a horizontal plate removes the humus layer.

The excavator used in this study was a small belt driven Hanix excavator equipped with a normal 50-cm bucket. The scarification consisted of digging up a bucket-full and inverting the profile. This scarification method is known as inverting site preparation (Fjeld, 1994; Örlander et al., 1998). The holes were 50 cm wide and 100 cm long, but mineral soil was spread over a larger area. The depth of the treatment was estimated to 50 cm at the deepest point.

In each of the 100 sub-plots, four sample plots of 1 m^2 (a metal ring) were systematically laid out. Three sample plots were placed on site prepared soil, and one was placed on unprepared soil, creating a total of 300 sample plots on site prepared soil and 100 sample plots on unprepared soil. The metal ring was used for all treatments meaning that also partly unprepared soil was included because the measured area was most often bigger than the site prepared area. The species and number of seedlings inside the ring was registered. The sample plots on site prepared soil was centred on the planting hole or strip while the measurement areas on unprepared soil was placed on soil without visible site preparation.

Analyses of the effect of site preparation on regeneration density was only performed on Norway spruce because regeneration density of the other species was either too sparse or too dependent on the location of seed sources. The weighted average number of Norway spruce seedlings pr. m^2 ($N_{average}$) in each subplot was calculated as $N_{site\ prepared} \times Pr + N_{unprepared} \times (1 - Pr)$. $N_{site\ prepared}$ is the average number of Norway spruce seedlings per m^2 in sample plots placed on site prepared soil, and $N_{unprepared}$ is the number of Norway spruce seedlings per m^2 in sample plots placed on unprepared soil. Pr is the weight between the two types of sample plots.

The difference between the treatments was analysed using the following model.

$$Y_{it} = \mu + \alpha_t + e_{it}$$

where Y_{it} is the observation, μ is the overall mean and α_t is the fixed treatment effects (t = 1, .., 6). The statistical analysis was performed using the GLM procedure in SAS for Windows 6.12. Bonferroni's t-test of differences between means was used to test differences between treatments. Both the block effect and the covariate, shelterwood density, were shown to be non-significant.

RESULTS

Seedlings of eleven different species were found on the site: Norway spruce, grand fir, willow (Salix sp.), birch (Betula pubescens Ehrh.), larch, Scots pine, rowan (Sorbus aucuparia), European beech, western hemlock (Tsuga heterophylla (Raf.) Sarg.), oak and sycamore. Norway spruce accounted for 98% of the seedlings (Tab. 1).

Table 1. *Distribution of seedlings and species in site prepared and unprepared areas.*

Species	Numbers counted		Proportion of total (%)		Weighted average numbers per ha
	In unprepared soil	In site prepared soil	In unprepared soil	In site prepared soil	
Norway spruce	2 030	13 174	98.6	98.2	275635
Grand fir	15	80	0.7	0.6	1820
Larch	0	18	0.0	0.1	191
Scots pine	2	15	0.1	0.1	347
Western hemlock	0	9	0.0	<0.1	137
Willow	2	59	0.1	0.4	1056
Birch	1	38	<0.1	0.3	662
Rowan	4	8	0.2	<0.1	375
Beech	3	5	0.2	<0.1	150
Oak	1	3	<0.1	<0.1	91
Sycamore	0	1	0.0	<0.1	7
Total	2 058	13 410	100.0	100.0	280471

The average number of seedlings was 41 per m^2 in prepared soil and 19 in unprepared soil. There was no regeneration at all in 2.8% of the prepared areas and in 7.4 % of the unprepared areas.

The lowest number of Norway spruce seedlings per m^2 in site prepared soil was found in plots prepared with manual removal of humus. The highest number was found in plots prepared with the Polyteknik drum rotator and the soil auger, but no significant difference was found between the five mechanical implements The lowest number of Norway spruce seedlings per m^2 in unprepared soil was also found in plots prepared with manual removal of humus. The highest number was found in plots prepared with the Loft disc plough, but again there was no significant difference between the mechanical implements (Tab. 2).

Table 2. *Norway spruce seedlings per m^2.*

Treatments	Seedling in site prepared soil (No. m^{-2})	Seedling in unprepared soil (No. m^{-2})	Weighted average of seedlings (No. m^{-2})
Manual removal of humus	10^{a*}	5^{a}	6^{a}
Soil auger	54^{b}	16^{ab}	27^{ab}
Kulla mill harrow	37^{b}	16^{ab}	21^{ab}
Polyteknik drum rotator	58^{b}	19^{ab}	29^{b}
Loft disc plough	45^{b}	34^{b}	39^{b}
Hanix excavator	44^{b}	20^{ab}	31^{b}

*In each column different letters indicate significant difference at $p<0.05$ level

DISCUSSION

The extent of natural regeneration is noteworthy on poor soil such as the one studied – a locality that was virtually treeless a century ago. The results show that during the past 100 years, it has been possible to establish a forest climate and to improve the soil to such a degree that natural regeneration now can take place.

The regeneration consists of eleven different tree species – of which six are native and five non-native. Seed sources of Norway spruce, grand fir (incl. silver fir), larch, and Scots pine were present in the original stand while willow, birch, rowan, western hemlock, beech, oak, and sycamore were not present, although seed sources of the latter species were present in neighbouring stands.

Site preparation increases the number of seedlings per m^2 for most, if not all, species, but the effect varies. Seedlings of larch, western hemlock, willow, and birch are present almost exclusively in the site prepared soil. Seedlings of Norway spruce, grand fir (and silver fir), and Scots pine occur in both site prepared and unprepared soil, but more abundantly in the site prepared soil. There are too few seedlings of rowan, beech and oak to evaluate these species, but they are able to germinate in site prepared soil as well as in unprepared soil.

The soil seems to be affected by site preparation even in areas where site preparation is not visible (i.e. in unprepared soil). Light compaction and humus layer disturbance of the soil caused by driving in the stand is one possible factor, which could explain the higher number of Norway spruce seedlings in plots prepared with the excavator, the Loft disc plough, the Polyteknik drum rotator, and the Kulla mill harrow compared with plots prepared with manual removal of humus. The higher number of Norway spruce seedlings in plots where site preparation were done with the soil auger is more difficult to explain because the soil auger operated from the striproad. It might be coincidental.

Natural regeneration of Norway spruce without site preparation using a shelterwood is possible, but the number of seedlings is much lower than after site preparation. In the actual study enough seedlings are found also in plots prepared with manual removal of humus, but in other cases with less favourable conditions site preparation might have been necessary to obtain enough seedlings. In the mechanically site prepared plots the high number of seedlings represents a potential problem because this could necessitate costly cleanings. This even though that the seedlings counted in this study were mainly two years old, and therefore it is reasonable to assume high mortality levels in succeeding years.

With the exception of manual removal of humus all types of site preparation damage some roots of the shelterwood trees and thereby reduce the physical stability of the stand (Fjeld 1996, Westerberg & von Hofsten 1996). From this point of view it would be desirable to be able to regenerate spruce stands without site preparation, which would also reduce regeneration costs.

The large number of Norway spruce seedlings makes it questionable as to whether it is possible to create a mixed stand: do other species have a chance to develop in competition with the all-dominant Norway spruce? Species like larch, birch, oak and Scots pine grow fast in the early stages, and they should be able to compete in the first many years, while species like silver fir, grand fir and beech would have to be favoured in cleanings before they can compete. The presence of other species than Norway spruce shows the potential, and sowing could be considered if natural seed sources of desired tree species are inadequate. Planting on areas without natural regeneration would be another way to introduce new species.

CONCLUSION

Looking at the weighted averages it is obvious that mechanical site preparation improves natural regeneration of Norway spruce compared with manual removal of humus.

The study has shown a positive influence of machines driving on the site making some slight humus and soil disturbance. A practical implication could then be to use for example ATV's (small four wheel driven machines)(Nordfjell 1995) with wheel chains and to drive systematically in the stand in order to improve the natural regeneration. It could be a cheap and lenient site preparation method in this type of stands.

Natural regeneration under a shelter of spruce is possible on former heathland in Denmark. A great variety of tree species are able to regenerate but the existence of seed sources plays a vital role for the mixture of species in the regeneration. With Norway spruce dominating the shelter stand, as well as adjacent stands, it is difficult to obtain a varied seed source. Site preparation improves natural regeneration of most species but enough regeneration might prevail without site preparation. Future studies are necessary to determine the specific conditions where it is possible to recommend regeneration by the use of shelterwood without site preparation as pointed out by Örlander and Karlsson (2000). According to this, it is important to be able to determine the survival rate of the natural regeneration within the ensuing few years.

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PAPER V

Single-tree and Group Selection in Montane Norway Spruce Stands – Factors Influencing Operational Efficiency

Kjell Suadicani and Dag Fjeld (2001)

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